ENHANCED TECHNIQUES FOR FINGERMARK RECOVERY FROM FABRICS

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CERTIFICATION

I certify that this thesis is the true and accurate version of the thesis approved by the examiners, and that all relevant ordinance and regulations have been fulfilled.

Signed …………………………………………… Date……………….

(Director of Studies)

DECLARATION

I, (Joanna May Fraser), declare that this thesis is the product of my own effort. I can confirm that where information has been derived from other sources, this has been indicated in the thesis.

Signed: ______________________________________ Date: ______________

(Joanna May Fraser)

"All of us take pride and pleasure in the fact that we are unique, but I'm afraid that when all is said and done the police are right: it all comes down to fingerprints."

David Sedaris (1997)

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Abstract

Fingermarks have been used for centuries as a means of determining an individual's identity and fabrics have long been considered a difficult substrate from which to visualise and collect fingermarks. This study mainly concentrated on vacuum metal deposition (VMD) and cyanoacrylate fuming (CAF), to ascertain whether these methods could visualise planted marks and consequently be used in the examination of clothing from assault cases.

Nine different fabrics: cotton, polycotton, polyester, nylon, nylon-Lycra, satin, silk, rayon and linen along with fifteen donors ranging in age, sex and ability to leave fingermarks were used during this work. The donors were previously tested on paper to determine their propensity to leave fingermarks, which gave an indication as to their donor ability level – poor, medium or good. The samples were collected and processed with the appropriate technique after a determined time interval, generally, 1, 2, 3, 4, 5, 6, 7, 14, 21 and 28 days, however this was altered for some of the trials.

From the results, it was found that both VMD and CAF did visualise marks and ridge detail from latent fingermarks. VMD was found to be the most suitable technique for development of fingermarks on fabric, with gold + zinc VMD best for light coloured fabrics and silver VMD for dark. CAF also visualised several identifiable marks, even with the problems of background fluorescence from the basic yellow 40 (BY40) dye used to visualise the cyanoacrylate (CA) polymer. Generally, it appears that the smoother fabrics with a tighter weave, such as nylon and silk allowed the visualisation of more detail than rougher and/or looser weave fabrics such as cotton and linen. The latter tended only to show empty marks or marks, which gave indications of where the fabric had been touched. However, fabrics that did show marks, even if not suitable for identification, could still give information as to the sequence of events that may have occurred during an assault as well as identifying an area to tape for DNA. It was determined that it was possible to collect DNA from VMD visualised marks which led to partial and full profiles of those who touched and grabbed the test swatches or items of clothing tested.

Though both VMD and CAF were affected by the addition of water to the surface of the fabrics being processed, marks and ridge detail were still detected, though CAF was less effective than VMD. With sequential treatment, it appears that the optimum sequence is VMD followed by CAF, due to enhancement of contrast between the metal deposits and BY40 yellow stained background. CAF then VMD only led to extra detail being observed on nylon-Lycra. There was limited success with 1,8-diaza-9-fluorenone (DFO), small particle reagent (SPR), ninhydrin, fluorescent powders or the sputter coater for alternative VMD metals. The production of nanoparticles was unsuccessful; so no fingermark visualisation was attempted. Finally, the issue of ridge detail being obscured by the fabric weave may have been resolved by the use of IR photography or FFT processing.

In conclusion, both VMD and CAF are viable processes for the development of fingermark and palm detail on fabric, clothing and textiles. It must be considered however that the donor and fabric being processed greatly affected the level of detail visualised. However, even if ridge detail is not visualised, any marks that are present could indicate a sequence of events or act as an area to target for DNA profiling.

Abbreviations

AWRE – Atomic Weapons Research Establishment

BY40 – Basic Yellow 40

CA – Cyanoacrylate

CAF – Cyanoacrylate fuming

CAST – Centre for Applied Science and Technology

DFO – 1,8-Diaza-9-fluorenone

FFT – Fast Fourier Transform

HOSDB – Home Office Scientific Development Branch

IR – Infrared

MEG - Monoethyleneglycol

MMD – Multimetal deposition

NAFIS - National Automated Fingerprint Identification System

NGM – Next Generation Multiplex

PCR – Polymerase Chain Reaction

PET – Polyethylene terephthalate

PITO - Police Information Technology Organisation

PP - Polypropylene

SEM – Scanning Electron Microscope

SGM – Second Generation Multiplex

SOP – Standard Operating Procedures

SPR – Small Particle Reagent

SPAFS – Scottish Police Authority Forensic Services (formerly Scottish Police Services Authority, SPSA)

SRBD - Scientific Research and Development Branch

tDNA – Touch DNA

VMD – Vacuum Metal Deposition

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1. INTRODUCTION

1.1 Background to fingerprints and fingermarks

1.1.1 Fingerprint history

Hand and fingermarks have been used for centuries as identifying marks, for example as signatures of individuals who did not know how to write. Ancient earthenware, thought to be at least 6000 years old was found to bear clear prints containing ridge detail and in ancient China documents were sealed with string and clay discs, which would have the author's name stamp on one side and their fingermark on the other (Barnes 2011). Pepper (2010) states that Nehemiah Grew was the first Western individual to describe the ridge patterns on the palms and soles in his 1684 paper. However, in 1687 Marcello Malpighi published a treatise, "Concerning the External Tactile Organs", in which he discussed friction ridge skin and how it helped humans to grasp and walk. It was not until J. C. A. Mayer in 1788 that the friction ridge individuality and uniqueness was discussed "Although the arrangement of skin ridges is never duplicated in two persons, nevertheless the similarities are closer among some individuals. In others the differences are marked, yet in spite of their peculiarities of arrangement all have a certain likeness" (Barnes 2011, p. 1-6). This was further elaborated upon in 1823 by Johannes E. Purkinje in his published thesis in which he described nine different fingerprint patterns [Figure 1.1] – (A) transverse curve, (B) central longitudinal stria, (C) oblique stripe, (D) oblique sinus, (E) almond whorl, (F) spiral whorl, (G) ellipse or elliptical whorl, (H) circle or circular whorl and (I) double whorl.

Figure 1.1: Purkjnje's nine fingerprint pattern types – (A) transverse curve, (B) central longitudinal stria, (C) oblique stripe, (D) oblique sinus, (E) almond whorl, (F) spiral whorl, (G) ellipse or elliptical whorl, (H) circle or circular whorl and (I) double whorl. (Barnes 2011, p. 1-10).

However, it was not until 1880 and the work carried out by Dr Henry Faulds that these patterns were considered of use in identifying individuals. Faulds witnessed that different patterns could be observed on the fingers and that even if the outer layers of the skin on the fingertips were removed they would regrow as the skin recovered from the injury. Thus, the fingerprints were persistent and unchanging, so could be used for identification purposes in criminal cases. Sir William Herschel agreed that fingerprints were unchanging, even taking his own prints during his adult lifetime. He also noted that prints could be used for identification purposes. At the time (1858) he was working as a Civil servant in India and he would have employees leave their handprint on the back of their contract, so each individual could be distinguished when they came to collect their pay. He also got prisoners to leave their fingermark next to their name in order to prevent others serving the prison sentence in place of the guilty person (Pepper 2010; NSTC 2006; Gaensslen, Harris and Lee 2008). In 1892 Sir Francis Galton published a book, "Finger Prints" and described how to classify fingermarks using different pattern types and minutiae (Galton details). He also believed that prints were unchanging, and thus could be used to identify individuals and he even calculated that the likelihood of two individuals having the same fingerprints was "64 million to 1" (Jackson and Jackson 2011, p. 108). It was the work carried out by Galton and Faulds that led Sir Edward Henry, along with Azizul Haque and Hem Chandra Bose, to develop a system of classification, using the three basic fingerprint types (loops, arches and whorls) augmented by minutiae or Galton details. In 1901 Henry became an assistant commissioner at the Metropolitan Police where his system was used by the newly set up fingerprint bureau. Previously a combination of Bertillonage, a system of 11 body measurements, such as arm length, head size and arm span as well as Galton's system was being used, though this was deemed unsatisfactory. It was a year later, in 1902, that fingermark evidence was first recorded in the case of a robbery where Harry Jackson was identified from a mark left in fresh paint which indicated that he had been at the house (he had been in prison before therefore could be identified from his records). By the 1930s the Henry system of the 10 print cards, which gave a permanent record of all 10 fingertips and marks, was being used worldwide by over 50 bureaux. A modified version of this system is still in use in Britain today, though has now become computerised in the form of IDENT1 and LiveScan. Though in other parts of the world it was Juan Vucetich's system that was used – Vucetich studied Galton's work and devised a classification system that was used to individualise and identify criminals and prisoners. An example of the use of fingermarks to solve a case is the 1892 case of Francisca Rojas – her two children were murdered and she had her throat cut. Francisca blamed a man she had spurned, however a bloody thumbmark was found at the crime scene and identified as being Francisca's and she confessed that it was in fact her that had murdered both her children and cut her own throat (Barnes 2011). Through history there have been several cases where fingermarks have been the only or most significant evidence used to convict – 1902 Alphonse Bertillon identified Henri Leon Scheffer as the murderer of Joseph Reibel from some bloody fingermarks on a broken glass panel; in 1905 the case of Alfred and Albert Stratton was the first case in England where fingermark evidence was used to convict the brothers of double murder on eyewitness testimony and Alfred's thumb mark on a cashbox and its 11 points of comparison and the 1911 burglary case of Crispi who was convicted on a fingermark on a pane of glass (Barnes 2011). All of these cases illustrate the uniqueness of fingerprints and the effectiveness in which their identification can help solve crimes and is still relevant even to this day. It should be stressed however, that the presence of fingermarks at a locus does not indicate or prove criminal activity, only that the person has been at this location to be able to leave their fingermarks there. Research in the area of fingermarks has been around for centuries and will be for many years to come with the advancement of commonly used fingermark visualisation techniques and discovery of new methods of fingermark enhancement.

1.1.2 Skin formation

Humans all have the same skin structure consisting of epidermis [Figure 1.2], dermis and subcutaneous layers, which over most of the body, is relatively smooth. However, notable exceptions are the palms and fingers of the hand as well as the sole and toes of the feet. These areas are called friction skin and though they appear different to the rest of the skin surface, due to their ridged appearance, they are composed of the same structural units.

The epidermis is the top layer and comprises five flattened or squamous epithelial layers – the stratum corneum, stratum lucidum, stratum granulosum, stratum spinosum and stratum germinativum. The stratum corneum, also known as the horny layer, is the thickest of the layers composing of approximately 30 layers of dead flattened keratinised cells that do not contain a nucleus. As this is the top layer of skin it is continually shedding cells and these are replaced by cells from the layers below

(Godfrey 1992; Droual 2012). This layer forms a barrier to protect the layers below from chemicals, infection and the skin drying out (Girod, Ramotowski and Weyermann 2012). The stratum lucidum layer is not present everywhere but usually found in the areas of thicker skin, such as the soles and palms. The cells are again flattened, may not contain nuclei and are transparent. Therefore, this layer will be present in the hands and will be part of the friction ridge skin. The stratum granulosum is usually only about 4 layers thick and contains granular cells, which contain a precursor to keratin and may still have nuclei and other cell bodies and this is considered to be where cells start to die. The stratum spinosum or prickle cell layer (due to the being covered by fibrils), is thinner and the cells are starting to become flattened. The final layer of the epidermis is the stratum germinativum also known as the basal or malpighian layer, which is a single layer of cells that are still actively dividing, contain nuclei and are in direct contact with the dermis.

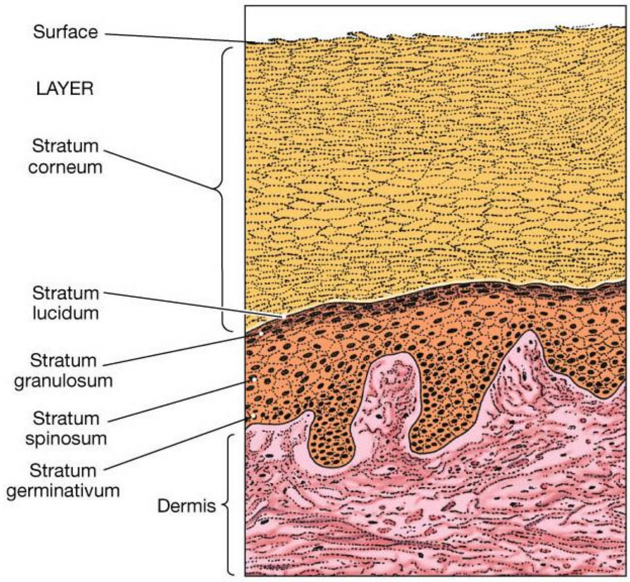


Figure 1.2: Layers of the epidermis, showing structural order starting at the skin's surface with the stratum corneum, then stratum lucidum, stratum granulosum, stratum spinosum, stratum germinativum and finally, the dermis (Droual 2012).

The dermis comprises of two layers containing all the blood vessels, nerves and sebaceous and sweat glands – the papillary layer, which contain papillae that help with exchange of oxygen, nutrients as well as waste and the reticular layer, containing fibroblasts, mast cells, collagen, elastin and reticulum which help the skin stay supple, resilient as well as keeping the dermis connected to the epidermis.

The subcutaneous layer is the final layer and is positioned close to the internal organs, thus allowing for the skin to move over these organs and it comprises of fat cells and connective tissue (Godfrey 1992; Droual 2012).

1.1.3 Formation of finger and palm prints

Fingerprints are formed in the womb and are unique and unchanging throughout a human's life, only increasing in size from child to adulthood. The only other alterations that may occur are through deep injury or disease. By the fourth week of gestation a recognisable hand starts to form, as opposed to the paddle like structures that first appear in the foetal growth from zygote to embryo [Figure 1.3]. Then, usually starting in the eighth week of gestation, swelling of mesenchymal tissue known as volar pads occurs and this is where the fingerprints are formed. There are eleven of these volar pads on the surface of the hand [Figure 1.3] and how they develop can be affected by many factors, such as genetics, disease, nutrition, chemicals, physical and environmental factors in the womb (Wertheim 2011, p. 3-8). The minutiae are formed as the foetus' fingers grow and expand causing these primary ridges to move apart, thus allowing new secondary ridges to fill the spaces between. This occurs at about week fifteen and is usually fixed by week sixteen, with the sweat glands maturing and the pores appearing on the ridges by the end of week seventeen.

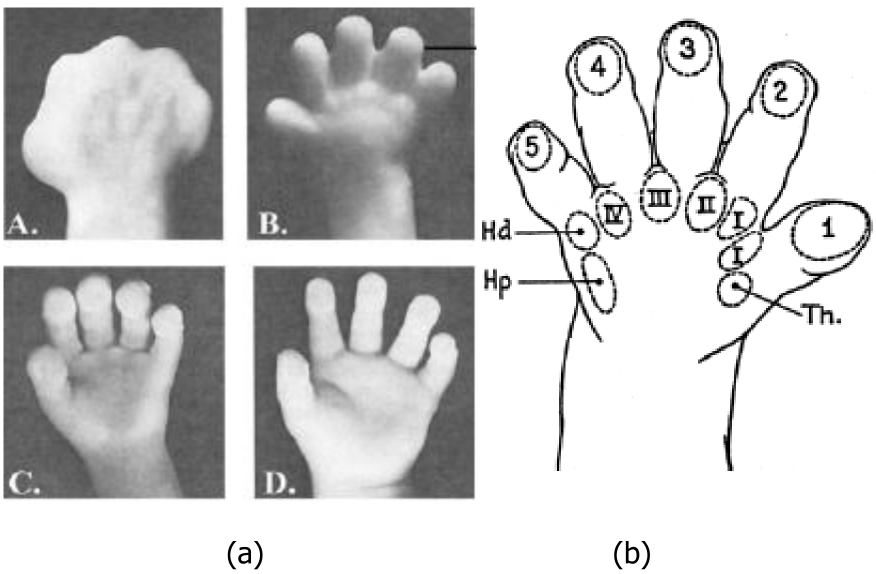
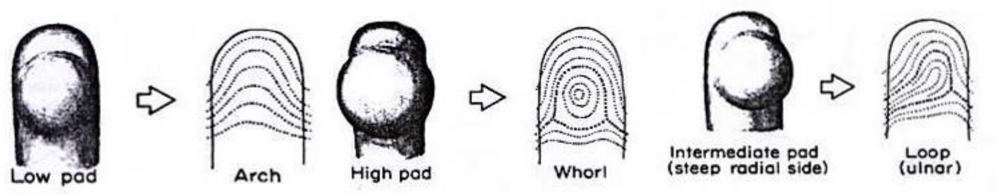


Figure 1.3: (a) Foetal growth and formation of hand in womb. A - Paddle form, B - Finger separation, C - Volar pads, D - Hand at 8 weeks. (b) Schematic of volar pads on developing hand - 1 to 5 (volar pads on the ventral apical regions of the digits; I to IV (interdigital volar pads on the palm); Hd (proximal hypothenar); Hp (distal hypothenar); Th (Thenar pad) (Wertheim 2011, p. 3-5 and 3-6).

The type of fingerprint that develops is dependent on the shape of the pads and the stresses caused by the growth and development of the hands – whorls and arches form symmetrical volar pads, with whorls forming from high round pads, while arches are produced from low pads. The ridges form around the centre or core of the volar pad and work outwards toward the edge of the finger. Loops form when the volar pads are asymmetric [Figure 1.4]. The three types of fingerprints, whorls, loops and arches form specific patterns though Babler (1987) comments that it is more to do with the width of the volar pads, where a small difference (9 mm) can produce a change from a radial loop to an ulnar loop. There is also the theory that the patterns are due to growth stresses and the folding of the basal layer in the epidermis (Kücken and Newell 2005).



(a) (b) (c)

Figure 1.4: Formation of fingerprint types from volar pads: (a) a low pad will lead to the formation of an arch, while (b) a high pad will produce a whorl and (c) an intermediate pad will lead to a loop being formed (Martijn 2012).

Whorls account for approximately 35 % of fingerprints and can be sub-classified into plain, central pocket loop, double loop and accidental whorl [Figure 1.5]. Whorls have the ridges circling the core of the print and have two deltas. The plain whorl has at least one ridge completely circling its core; a central pocket loop whorl has two deltas, but does not have a ridge encircling the core; the double loop whorl or twinned loop has two loops intertwined; and the accidental whorl is made up of a combination of the three other whorl types or a print that does not fit into any other fingerprint category. Loops account for approximately 60 % of fingerprints and have at least one ridge entering from one side, recurving and exiting from the same side, a minimum of one ridge count (number of ridges between the core and delta), only one delta and a core. There are two types of loops - ulnar (the open section of the loop points to the ulnar bone, at the little finger side of the hand) and radial loops (the open section of the loop points to the radial bone, the thumb side of the hand). Arches account for approximately 5 % and have their ridges entering from one side and exiting from the other, this type of print has no deltas. There are two types of arches

– plain and tented. Plain arches form a smooth flow of ridges from one side of the print to the other, while tented arches form an arch of about 90 ° or have a central ridge pointing upwards in the centre of the print (Davey 2003; Barnes 2011; Jackson and Jackson 2011).

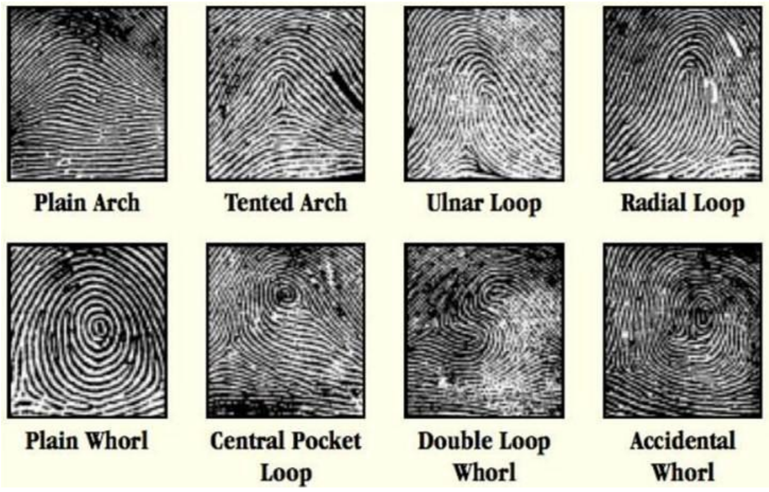


Figure 1.5: The eight general fingerprint pattern types of plain arch, tented arch, ulnar loop, radial loop, plain whorl, central pocket whorl, double loop whorl and accidental whorl (FBI 2012).

There are three levels in finger identification – level 1 detail, which is the fingerprint type; level 2, which is the Galton detail or minutiae; and finally level 3, which includes the palmar flexion creases, number of pores, their location and shape as well as the size and shape of ridges (Gaensslen, Harris and Lee 2008). There are many types of minutiae [Figure 1.6] – ridge ending, bifurcation, island or independent ridge, spur, lake and crossover. A ridge ending is where the ridge stops; a bifurcation is where one ridge splits into two ridges; an island or independent ridge is a short ridge; a spur is where a ridge has a small ridge extending from it; a lake is where a ridge splits and then re-joins again and finally a crossover is where two ridges are joined by a smaller ridge.

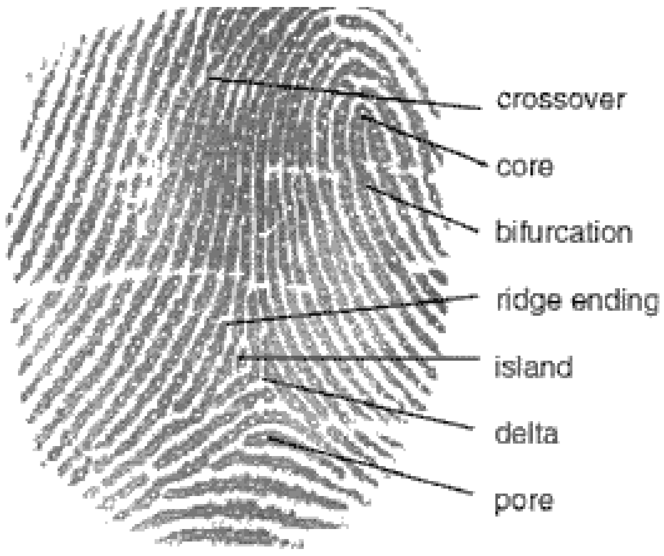


Figure 1.6: Fingermark containing four types of minutiae as well as a delta, a pore and a core. The minutiae are: a crossover, where one ridge joins another; a bifurcation, where the ridge splits into two; a ridge ending, where the ridge stops; an island, which is an extremely small short ridge; the core is the centre of the print; while the delta is a point on the print at or near to where two ridges diverge; and the pore is where the fingerprint residues are released onto the surface of the skin (Alga 2002).

The formation of the lines on the palm also occurs during gestation between weeks six and eleven, when the creases form between the volar pads and it is thought to be caused by the foetus grasping its hands. There are several different lines formed on the palms, such as vestiges on the thena, which flow at right angles to the rest of the ridges on the palm and flexion creases. They are split into three main types – major flexion creases, minor flexion creases and secondary creases. The major creases are, as the name suggests, the largest creases on the hand and they run transversely across the palm. These three creases are called the thenar or radial transverse (also known as the life line), proximal transverse (the head line) and distal transverse creases (the heart line). They can appear as deep solid lines or made up of smaller creases (accessory creases). The minor creases are not always present or pronounced as the major creases and can be split into several types: minor flexion creases; longitudinal or finger creases, which run from the base of the fingers to the wrist; accessory distal transverse creases and the hypothena crease; finally the secondary creases are all the other creases on the palm (Davey 2003; Dhananjay, Guru Rao and Muralikrishna 2011). Palm marks are also useful in the sense that they are larger than fingermarks so they too can be used for identification purposes as they contain a lot of information – palmar flexion creases, principal lines, deltas, ridges and pores (Nibouche and Jiang 2013).

As well as having different classifications of marks there are also three different types of marks – visible, plastic and latent. Visible marks are those that can be seen by the naked eye and therefore do not need any form of enhancement. They can be formed by an individual transferring paint, blood, oil, cosmetics or other substances from one substrate to another via their fingertips and leaving a mark on a substrate. Plastic marks are formed when an individual leaves an impression of their mark in a soft substance such as putty, food or wax. These marks form a three dimensional impression of the person's fingertip and therefore ridge detail. Consequently they do not generally need enhancement, though in some cases enhancement may make the mark more obvious. Finally, latent marks are marks that are not visible to the naked eye and need to be enhanced in some way to make them visible using suitable lighting, physical or chemical treatments (Gaensslen, Harris and Lee 2008).

1.1.4 Composition of fingerprint residues

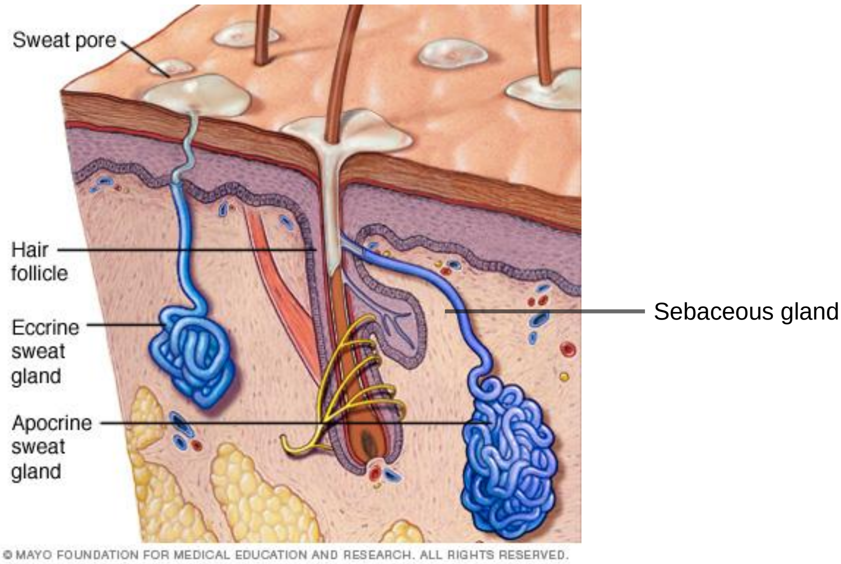


Figure 1.7: Cross section of the human skin illustrating the two types of sweat glands (eccrine and apocrine) and sebaceous glands. The eccrine glands open directly onto the skin's surface, while the apocrine and sebaceous glands open into the hair follicle (Mayo Clinic 2013).

The form of visualisation treatment to be used on a latent mark is dependent on which component in the mark is to be targeted. There are three different types of glands producing secretions that can be found in marks – eccrine, apocrine and sebaceous [Figure 1.7].

The eccrine gland is found over almost the entire body and produces secretions comprising mostly of water with other constituents such as sodium chloride, urea, amino acids and hormones, as illustrated in Table 1.1.

Table 1.1: Components of fingerprint residues, including their source (eccrine, sebaceous or apocrine gland), whether the constituent is inorganic or organic and the approximate percentage. This is adapted from the Home Office Scientific Development Branch (HOSDB) Fingerprint development handbook (Bowman 2005) and the review by Girod, Ramotowski and Weyermann (2012).

Source	Constituents of fingerprint residues (quantities)		Percentage of print residue
	Inorganic	Organic	
Eccrine glands		Water	~95 %
	Chlorides (1-15 µg)	Amino acids (0.2-1 µg)	~5 %
	Metal ions	Urea (0.4-1.8 µg)	
	Ammonia (0.2-0.3 µg)	Lactic acid (9-10 µg)	
	Sulphates (0.02-0.2 µg)	Sugars	
	Phosphates	Creatinine	
		Choline	
		Uric acid (150 µM)	
Sebaceous glands		Fatty acids	
		Glycerides	
		Hydrocarbons	
		Alcohols	
Apocrine glands	Iron	Proteins (384 µg)	
		Carbohydrates	
		Cholesterol	

The apocrine glands are found exclusively in the armpits, genital area, nipples, as well as the eyelids and around the nostrils. The secretions from these glands are oily, containing proteins and lipids; though they are odourless when first excreted, interaction with bacteria once on the skin surface produces the characteristic scent of body odour. Both the eccrine and apocrine glands are primarily involved in thermoregulation of the body, cooling the body down when it becomes too hot due to emotional or physical stress. This thermoregulation of the body and stresses are important when considering criminal investigations as there may be a presumption that a person involved in criminal activity may experience heightened emotions or stresses, which in turn may lead to increased levels of secretions. Therefore, marks left at a crime scene may contain higher levels of the secretions from the eccrine and apocrine glands. Eccrine and apocrine glands also excrete waste products, which can include drugs and their metabolites. Thus drugs can be detected in latent marks and this has been extensively researched. For example, Day et al. (2004) detected several drugs including codeine phosphate, cocaine hydrochloride, caffeine and Paracetamol in cyanoacrylate (CAF) visualised marks; while Hazarika, Jickells and Russell (2008) found cotinine in smoker's latent marks and the Ng et al. (2009) study detected caffeine in marks.

The sebaceous glands produce sebum, which is involved in keeping the skin supple, helps in waterproofing and prevents bacterial growth. These glands are usually connected to hair follicles and are mostly on the face and scalp, though they can be found in other areas such as the nose, eyelids and genitals.

Therefore, the main components of latent marks, a mixture of water, oils from the body and hair as well as contaminants, such as foodstuffs and make-up are released onto the skin from the sweat pores. These secretions are transferred from the fingers and/or palm onto substrates and, consequently, marks are deposited, and can be visualised and recorded.

The need to consider the composition of the marks is important as once they are deposited on a substrate the levels of the components can change. Water evaporates, while other components degrade, therefore it is important to understand this, as well as the substrate type, when the process of visualisation is considered (Champod et al. 2004). There are several factors, such as the individual's health, profession, age and even sex, which can influence the level of residues deposited onto a substrate. Then, once the residues have been deposited environmental factors, such as temperature, humidity and the time they are on the substrate can also affect the levels and how long they remain on the substrate (Ramotowski 2001; Yamashita and French 2011). Therefore not everyone will leave the same levels of the components expected to be found in a fingermark, and the environment will have an effect on the levels and how long they can be detected in the mark. For example, the levels of fatty acids in the sebum and therefore in latent marks varies with the age of the person. In infants the levels of fatty acids are 1.5 %, rising to 20-23 % in children under 4 and dropping to 16-19 % in adolescents and those under 45. The same can be seen with other lipids, such as glycerides, fatty esters and cholesterol in sebaceous secretions, which all change in levels throughout a person's lifetime (Yamashita and French 2011).

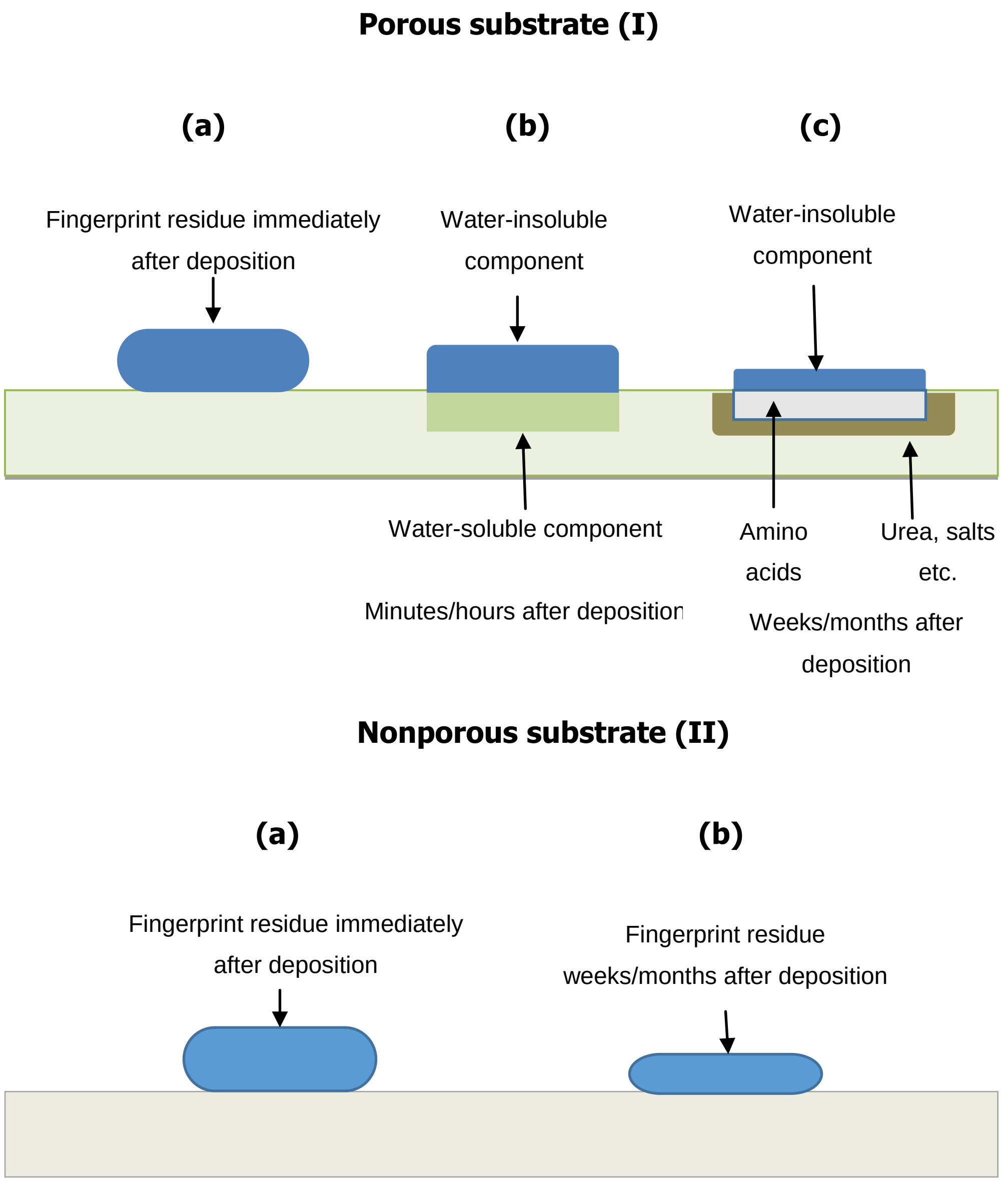


Figure 1.8: Ageing of latent fingermarks showing the effect of time on the residues deposited on I a porous substrate: I(a) immediate deposition; I(b) minutes/hours after deposition; I(c) weeks/months after deposition and II(a) on a nonporous substrate immediately after deposition and II(b) weeks/months after deposition (adapted from Champod et al. 2004, p. 110).

Latent marks left on substrates consist of a combination of the secretions of all the different glands in the skin. The largest component, as illustrated by Table 1.1 on page 10, is water and this will start to evaporate as soon as the mark is deposited, leaving the other components, such as the water-soluble salts and amino acids as well as the water-insoluble proteins and lipids. It is these components that the different visualisation techniques target, such as powders for water, ninhydrin for the amino acids and physical developer for the lipids (Yamashita and French 2011). The precise location of the components depends on the porosity of the substrate, for example, on a porous substrate the water-soluble components will soak in, while the water-insoluble components will sit on the surface of the substrate. With a nonporous substrate all the components will sit on the substrate's surface and be affected by evaporation rather than being absorbed by the substrate [Figure 1.8] (Champod et al. 2004).

Fabrics are generally considered to be porous substrates though this depends on the chemical composition of the fabric and whether it is natural or manmade. These factors will dictate how absorbent the fabric is and thus how much of the fingerprint residue will be absorbed into the fabric or remain on the substrate's surface. The rate at which the residues evaporate from the surface of the substrate is dependent on its porosity as well as on several environmental factors, such as humidity, sunshine, wind and temperature (Champod et al. 2004). Over the first two weeks of mark deposition there can be up to an 85 % reduction in weight and this is primarily due to loss of water and then the remainder of the components are subject to such processes as degradation, migration and oxidation (Girod, Ramotowski and Weyermann 2012). Holyst (1987, cited in Champod et al. 2004, p. 199-201) stated that ageing and thus lifetime of a mark is dependent on many factors: temperatures, low humidity, light exposure and even dust. Also, a mark may last 15 times longer when kept indoors rather than outdoors and that greasy marks last five times longer than sweaty marks. How much of each component is lost is dependent in some part on the substrate as marks tend to stay best on nonporous smooth substrates, such as glass, metal and plastics. However, residues that are on a non-porous surface can be more easily wiped or washed off that substrate than residues that have penetrated to some degree into the substrate. This again is reinforced by the Girod, Ramotowski and Weyermann (2013) review where the combined studies showed that on porous substrates, such as paper and cotton, eccrine secretions are absorbed easily into the substrate, whereas sebaceous secretions are absorbed more slowly. Semi-porous substrates, such as plastics and glossy paper absorb eccrine secretions more slowly than on porous substrates and sebaceous secretions were extremely slow to be absorbed. On nonporous substrates, such as metal and glass, both eccrine and sebaceous secretions remain on the substrate's surface until biological, chemical or physical degradation occurs. Research into environmental effects on latent fingermarks has been carried out for decades and advances made into mark survival under different conditions and substrate surfaces. Barnett and Berger (1977) investigated the effect of temperature and different levels of humidity. Their study had a one day to 7 week timeline with marks being deposited on glass microscope slides, dusted, lifted and graded by two individuals. Overall, there was a significant difference between the natural or clean marks and the loaded or greased marks as well as dirty marks, with the clean hands scoring higher. They also found that the number of useable good marks decreased during the timeline and that high humidity impacted poorly the grade the marks achieved, whereas low humidity did not seem to cause a detrimental effect. Interestingly, temperature (20 °C and 30 °C) did not seem to have a significant effect on the difference between marks that were developed immediately and the overall score during the whole timeline. The effect of moisture in the form of humidity, dew and rain may also be influential. Johnson (1973) determined that high humidity may prevent or slow evaporation of water from the mark or even prevent development of the mark, whereas low humidity may speed evaporation of the mark. Rain, however, can wash away fingerprint residues or prevent a mark from being deposited if the substrate is wet. Dew dissolves enough of the water-soluble residues in a mark, causing it to be diminished and/or distorted. This causes them to be diluted and spread over the substrate's surface; however, if the mark is laid onto a dew soaked substrate it may not adhere to the surface at all.

Overall, there are many factors that need to be considered when attempting to visualise fingermarks and grab marks from a variety of substrate types. It can be concluded that secretions on fabrics will be absorbed and therefore less detail visualised. However, as discussed in the section 1.2.1, fabrics will have different porosities due to their chemical and physical composition and latent fingermarks on fabrics will be affected by environmental conditions, donor deposits as well as contaminants on the donor's hands.

1.1.5 Permanency and uniqueness of prints

As discussed previously, fingerprints are formed in the womb, are unchanging throughout a person's life and are unique to each person; even identical twins do not have the same fingerprints. Two papers published in Pattern Recognition (Jain, Prabhakar and Pankanti 2002; Kong, A. W., Zhang, D. and Lu, G. 2006) discuss the similarities in fingerprints and palmprints in relation to the use of biometric verification. As identical twins result from the splitting of a single egg they have the same DNA, thus will be extremely similar genetically but as they do not occupy the same position in the womb they are exposed to different environmental factors, thus will develop different fingerprints, palmar flexion creases, iris and retina. It has been found that twins may share fingerprint types or have similar principal lines, for example if one twin has a whorl on their ring finger, so might their twin, however the minutiae will not be the same.

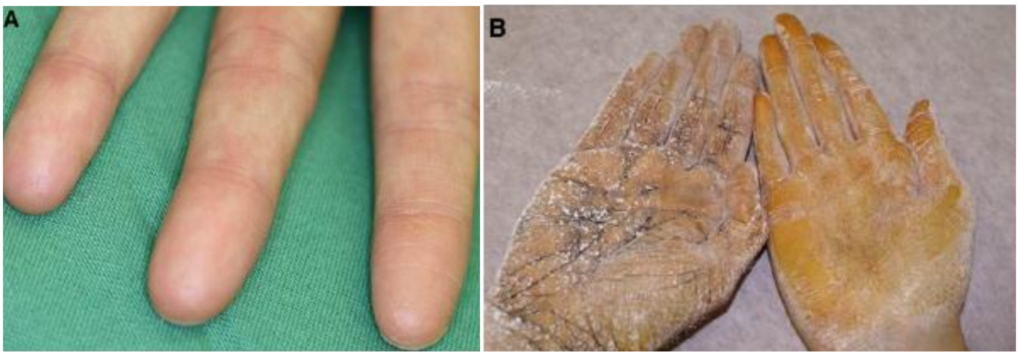


Figure 1.9: Image A shows the absence of fingerprints on a person with adermatoglyphia, while image B shows the results of a sweat test, demonstrating the reduced sweat production in a person with adermatoglyphia (right hand) and a normal level of sweat production in a person without adermatoglyphia (left hand) (Nousbeck et al. 2011).

Changes can occur in the case of conditions or diseases such as adermatoglyphia, scleroderma, psoriasis, eczema leading to the loss of fingerprints. Treatment for cancers, such as chemotherapy, which leads to hand-foot syndrome or chemotherapy-induced acral erythema as well as burns and trauma, may also affect fingerprints (Harmon 2009). In the case of adermatoglyphia the skin lacks epidermal ridges, thus is smooth and the person lacks fingerprints from birth. This is due to the lack of expression of the SMARCAD1 gene and the individuals can also display skin blisters, facial milia and possess a lack of sweat glands as demonstrated by the sweat test [Figure 1.9]. This is quite a rare condition only being noted in four families and has become known as the "immigration delay disease" due to the problems these individuals face when they try to enter countries requiring fingermarks to be taken as a form of identification (Nousbeck et al. 2011). The other conditions occur with individuals that were born with fingerprints, but they disappear due to swelling of the skin, for example with the chemotherapy-induced acral erythema the treatment causes swelling of the skin, which in turn causes the friction ridges to be smoothed out. This does not occur with all patients and can be relieved by topical lotions and vitamin E treatment (Hueso et al. 2008).

Nevertheless, even if an individual possess prints, which are permanent, the quality of fingermarks left are affected by many things, such as dryness of skin, cuts, scars, even contaminants on the skin, but a major factor is the effect of age. There can be a reduction in ridges due to the person's job, accidents, as well as an increase caused by wrinkles from ageing. Thus there can be false minutiae that may be temporary or that will become permanent, which in turn can affect the identification due to alteration of the overall print. The prints are still unique to this person, though they have changed in the sense that there may be an increase or decrease in detail. Zhou et al. (2009) investigated this very issue with a computer program which detects creases and removes these false minutiae to aid in fingerprint recognition and matching. These age wrinkles can be seen in Sir William Herschel's prints where he took his own prints as well as others throughout his life and he found the overall pattern was the same and unchanged. This is illustrated in Figure 1.10 showing the only changes are the addition of wrinkles from ageing.

Figure 1.10: Fingerprints of W. J. H. taken by Herschel in 1859, 1877 and 1916, showing the ridge detail and fingerprint type of this individual over time and illustrating the only changes were the additions of wrinkles from ageing (Herschel 1916, p. 30).

There have of course been cases of individuals attempting to alter their prints for one reason or another by either the addition of glues, silicone, nail varnish or latex even by damaging their prints by burning or cutting. A famous example of this is John Dillinger, a bank robber during the 1930s, who dipped his fingers in acid to burn off the prints, however this was not worth all the pain he endured as faint ridge detail did return after the fingertips recovered. Another example of a criminal trying to evade the authorities by altering his prints is Robert J. Philipps, who grafted skin from his chest onto his fingers. Though this did obliterate his fingerprints he was identified by the skin on his finger joints and the areas around the grafts. Nowadays though criminals are still trying to obliterate their prints, as in the cases of drug dealer Marc George who grafted skin from his soles to his fingers and Jose Izquierdo [Figure 1.11] who performed a Z cut – triangular cuts to the fingertip, swapping the patches and then stitching back together, but there seems to be many more people doing this to try to avoid identification at border control. These changes involving Z cuts, altering with lasers and swapping prints from one finger to another, which does of course change the prints, but again makes them more individual and unique, thus identification is still possible and in many cases the unusual appearance of the prints causes suspicion and investigation (BBC 2012; Yoon, Feng and Jain 2012).

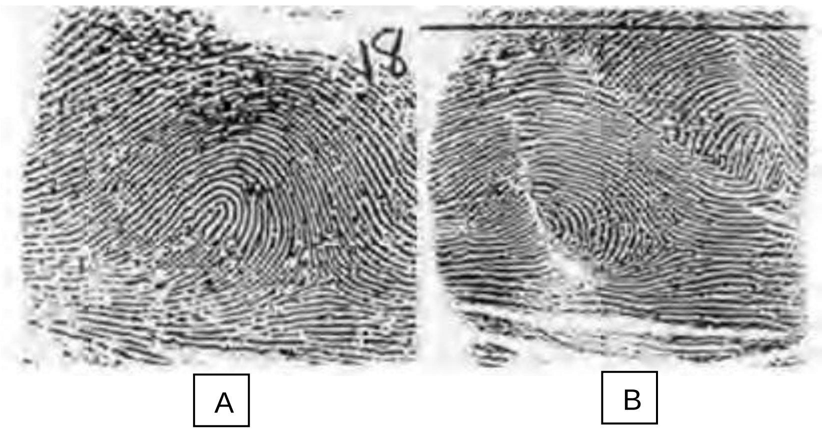


Figure 1.11: "Z" cut fingerprint of Jose Izquierdo. (A) showing his original fingerprint and (B) after being altered by cutting a "Z" shape where two parts of the skin are moved to form a different pattern (Yoon, Feng and Jain 2012).

1.1.6 Use of fingermarks and palms in identification

As previously stated a modified Henry's 10 print system is still being used in fingerprint identification systems, such as IDENT1 and LiveScan. All of these methods use detail in the form of ridges, direction of flow, orientation, location, minutiae as well as 3rd level detail, such as sweat pores and the spaces between the ridges, to lead to identifications from 10 print cards and marks from scenes of crime. This is also the case with information gleaned from palm marks which also contain friction ridges, valleys and minutiae with palms also showing palmar flexion creases. The Australian NAFIS is said to be the largest in the world and contains approximately 11 million palm marks (CRIMTAC 2011), while in the UK IDENT1 contains approximately 12 million palm mark pairs (Wormack 2012). The use of palm marks in identifications is important when you consider that about 30 % of all marks recovered from different scenes of crime in America (Vacca 2007) and for the UK 20 % of all marks found in 2006 (Odyseos 2006) were palm marks, rising to 30 % in 2013 (Sutton et al. 2013). Therefore the inclusion of palm print capture to fingerprinting systems has been added to improve identifications. In 2001, the UK Police Information Technology Organisation (PITO) organised the development of a National Automated Palm system allowing all the police forces to be able to access palm mark records on a national database (Hurst 2002). LiveScan is used by most UK police forces to electronically record the marks of individuals arrested. These are then compared against the database and have been reported as being over 98 % accurate, thus reducing the time it takes to identify individuals involved in crimes (Pepper 2010).

1.2 Background to fabrics

Many crimes such as assaults, kidnapping and even theft involve fabrics at some point with clothing being the most common fabric seen in forensic laboratories (Adolf 1999). However, it is difficult to recover fingermarks from fabric due to the nature of its surface. The Home Office fingerprint manual states there is no "proven process" with fabrics for fingermark visualisation though it recommends that either radioactive sulphur dioxide or CAF is used. (Note: although still recommended in the most recently published manual the use of radioactive sulphur dioxide has been discontinued on Health and Safety grounds). The manual also states that the fabrics must have a minimum of three threads per millimetre, must not have been exposed to rain nor have been worn next to the skin for more than two hours (Bowman 2005; Fraser et al. 2011). The fabrics variously used in this study: cotton, polyester, polycotton, nylon, satin, rayon viscose, linen, silk and nylon-Lycra were chosen as they are commonly found in modern day clothing. Natural fabrics such as cotton are highly hydrophilic allowing sweat to be absorbed into the fabric and then enabling evaporation so ensuring the wearer stays cool and comfortable. Synthetic clothing, such as nylon are more hydrophobic meaning the sweat will collect on its surface making the wearer feel "clammy" (Wakelyn et al. 2007, p. 642). Therefore clothing fabrics and their uses are based on these properties as well as appearance and personal preference.

1.2.1 Fabric types

Cotton

Cotton is obtained from the shrub *Gossypium,* which is found in tropical and subtropical areas of the world, such as China, India, America and Africa. It is a natural cellulose fibre spun into tubular threads and then woven into cloth, from the protective soft ball produced by the shrub to protect its seeds (Wakelyn et al. 2007; Nanal 2012a).

Cotton has been used since prehistoric times in the form of clothing and accounts for approximately 38 – 50 % of all fibres used in the textile industry is still the most used natural fibre in clothing (Wakelyn et al. 2007; Nanal 2012a). Due to the properties of cotton it is used in many different clothing types ranging from hard wearing denim and T-shirts to more delicate items such as dresses, shirts and underwear. Cotton can be used on its own as well as being blended with other fibres, such as polyester to increase durability and elastane to increase the stretchiness of the fabric. Benefits of cotton are its softness, breathability, as well as its hydrophilic properties which allow absorbency of water (to the core of the fibre), thus making it easier to remove dirt and allowing an even absorbency of dye (FAO 2009; NCCA 2013).

Polyester

Polyester is a manmade fibre consisting of a long chain polymer usually formed by the polymerisation of terephthalic acid (TA), and monoethyleneglycol (MEG) in the presence of antimony trioxide and titanium dioxide [Figure 1.12].

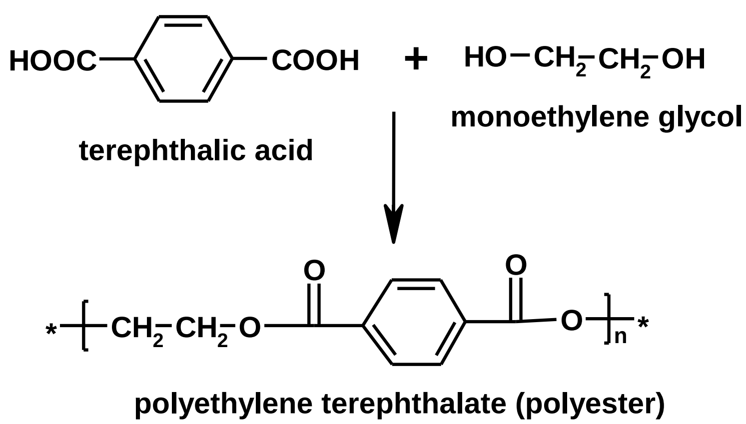


Figure 1.12: A polycondensation reaction of terephthalic acid and monoethylene glycol to form polyethylene terephthalate, more commonly known as polyester.

The fabric is durable, strong and generally water resistant, due to its hydrophobic nature. It protects the body from the cold as a result of the air inside the fibres which become warmed from the body and act as a heat insulator. Other beneficial qualities of polyester is its resistance to wrinkles, shrinking and staining, it is also quick to dry and therefore is the most used fibre in many items of everyday clothing. Today, microfibers and blends have made the fabric more comfortable and luxurious with a silk like feel and appearance thus this versatility makes it the most use fibre in the manufacture of clothing.

Polyester is generally a long smooth bright fibre, which can be flat, triangular, trilobal, hollow or dog bone in shape. It has cationic dyeability which allows bright acid dyes to add colour, though it may also contain delustrants to reduce the overall brightness of the fabric as the fibres can fluoresce under ultra violet (UV) light. It is also a high tensile fibre with a micro denier, making it extremely soft. Additionally, it can be used on its own or blended with cotton, wool or viscose rayon to produce fabrics with the properties of both fabric types (Nanal 2012b; Geno 2013).

Nylon

There are many different types of nylons, though the most commonly used in the manufacture of clothing is nylon 6 or nylon 6,6. Nylon 6,6 [Figure 1.13] is a synthetic polyamide produced by a condensation reaction between adipic acid and hexamethylene diamine while Nylon 6 [Figure 1.14] is formed by the ring opening polymerisation of ε-caprolactam (Trossarelli 2010). Both these nylons were developed at Du Pont in the 1930s and they were first used commercially in 1939 with the sale of stockings (Saunders 1998; Hegde et al. 2004).

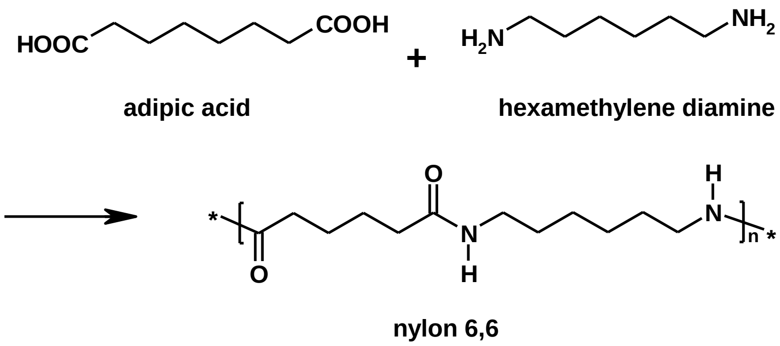


Figure 1.13: The production of nylon 6,6 from adipic acid and hexamethylene diamine.

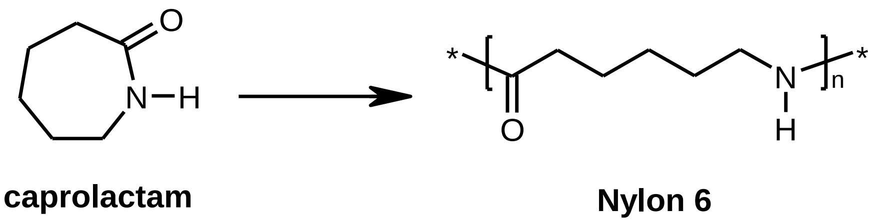


Figure 1.14: The production of Nylon 6 from caprolactam.

To produce the fibres the crude nylon is first melted, spun and cooled, and the resulting product is cold-drawn at room temperature through spinnerets, until they are approximately four times their original length. This in turn increases both the stiffness and tensile strength of the newly formed fibres, which have a higher tensile strength than natural fibres such as silk, cotton and rayon (Hegde et al. 2004).

Nylon is a strong fibre, which shows elastic as well as abrasion and chemical resistant properties. Unlike natural fibres such as cotton and wool which both absorb dye and water readily nylon can be dyed with difficulty though it does not absorb much liquid, due to its hydrophobicity. Nylon feels warm, is light weight, and is soft and smooth, even silk-like in feel, thus is good for a wide range of clothing (Hegde et al. 2004; AFMA/FEB 2012a). Nylon can also be mixed with other fabrics, such as the nylon-Lycra used in this study (80 % nylon and 20 % Lycra)

Satin

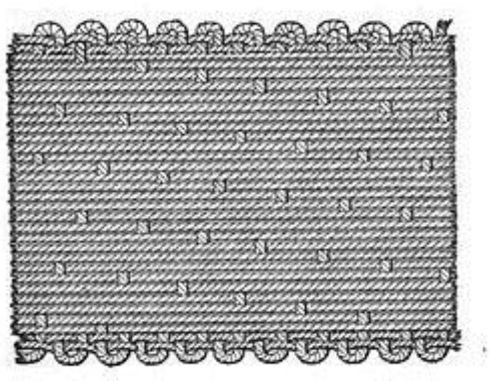


Figure 1.15: A satin weave demonstrating warp threads running side to side and the weft threads running top to bottom (Barlow 1879, p. 117).

Satin is not technically a distinct fabric, but a type of weave [Figure 1.15] consisting of broken twill, which has a shiny surface with a dull reverse. This is caused by there being a minimum of five weft threads lying or floating over the top of the warp, causing the shiny surface and the dull reverse to the fabric. Though this fabric can be quite heavy and originally in the Middle Ages made only from silk, it can be made in a variety of weights and fabric mixes, such as polyester, viscose and silk, thus has a variety of uses from evening gowns to bedding (Tikkanen 2010; Abrahart and Whewell 2013).

Viscose rayon

Rayon was the first discovered and manufactured in 1892, though was not commercially produced until 1910 as "Artificial silk". It is produced from regenerated cellulose, therefore has similar characteristics as cotton and is also known as viscose, acetate or alginate (Simmons 1978). Viscose rayon fibre can be woven into a soft, easy to dye, highly absorbent, breathable fabric that can be used in the manufacture of clothing ranging from lingerie to dresses and sportswear (Smith [no date]; AFMA/FEB 2012b). Rayon does however tend to have a strong lustre, due to its surface weave and the internal structures of the fibres so will reflect light quite readily unless delustring is carried out (Marsh 1966).

Linen

Linen is produced from fibres made from the flax plant, *Linum usitatissimum*, though it can also be made from cotton and hemp (Geijer 1979). Natural linen has a high lustre or sheen and can range in colour from light tan to grey which requires bleaching to form the white linen seen in much of the summer linens. There are two different types of flax linen fibre – short tow fibres, which produce rougher fabrics and the longer line fibres, which produce fine fabrics.

This fabric has been manufactured for centuries even as far back as prehistoric times and it is known that the wrappings on Egyptian mummies were linen. Nowadays, linen is used to make summer shirts, dresses and trousers due to the fact that the fabric allows the wearer to stay cool in hot weather, as well as absorbing water quite easily (up to one fifth of its dry weight, without feeling damp) and then drying out quite quickly. Even though the fibres are strong and shrink very little, the fabric does however crease quite easily and can become worn quite quickly in the creased areas as the fibres do not stretch (Anon [no date]; Geijer 1979).

Silk

Silk was first produced in China as far back as 3500 BC, as a luxury cloth and today China is still the leading silk producer in the world. The production of silk is called sericulture and involves the raising of the silk moth (*Bombyx mori*) through its full lifecycle from moths, to eggs, to worm, to the pupa or cocoon. The latter is formed by the worm secreting the silk thread, comprised of fibroin and sericin, which is wound around itself to form a cocoon. The way in which the silk worms produce a cocoon is from two glands in their head which produce a viscous liquid, which is forced through ducts similar to the spinnerets in the production of man-made fibres. The resulting fibres have a high tensile strength, even stronger than steel and unusually for fabric fibres, silk still maintains 80-85 % of its strength when wet (Trevisan et al. [no date]; Geijer 1979). The appearance and the ability of silk to keep the wearer cool in hot climates and warm in colder climates means it is used in a diverse range of clothing (Winter Silks 2013).

1.2.2 Moisture absorption and porosity of fabrics

All fabrics will absorb moisture from the atmosphere, but the amount absorbed depends on the ambient conditions, temperature and the humidity as well as how hydrophobic or hydrophilic the fibres are which relates to both the chemical and physical characteristics. The amount of water that is absorbed can be expressed as a percentage and is termed moisture regain.

$$\text{Moisture regain} = \frac{\text{Conditioned weight} - \text{Dry weight}}{\text{Dry weight}} \times 100\ \%$$

If a fibre is hydrophobic the moisture regain will be close to zero as it tends to repel water and moisture, whereas a hydrophilic fibre attracts water therefore will have a higher moisture regain - up to 15 % at 21 °C and a relative humidity of 65 %. Natural fabrics such as cotton and rayon are hydrophilic, thus have the ability to absorb moisture readily, this also means they are easier to process, to finish and dye, especially if aqueous dyes are used. Synthetic fibres such as nylon and polyester tend to be hydrophobic and do not absorb moisture to any high level, which in turn makes it quicker drying (Needles 1981). This means that fabrics have different uses due to these properties (Wakelyn et al. 2007, p. 642).

1.2.3 Fabric fingerprinting in forensic science

Fabric has always been considered a difficult substrate on which to visualise fingermarks and consequently processing for fingermarks is rarely carried out operationally unless the marks are visible. However, over the years there have been several fingerprinting techniques investigated for the acquisition of fingermarks from fabrics. Vacuum metal deposition (VMD) was studied in the 1970s by Hambley (1972), as well as the Atomic Energy Research Establishment (AWRE), for acquiring fingermarks from fabric (cotton, taffeta, rayon and nylon) with the sequential use of gold followed by cadmium resulting in a grey colouration on all areas except those where the fingerprint ridges were (Godsell 1972; Thomas 1978). It was observed by Collins, Coles and Stroud (1973) that there was no development on nylon-chiffon, taffeta and rayon-satin only showed empty marks but both white cotton lawn and patterned cotton satin allowed the development of good ridge detail. Thomas (1973) found that marks could survive heavy rain and temperatures up to 25 °C, though the detail visualised was donor dependant, however only one fabric type was used during the study. Further tests were carried out using a Bell jar vacuum container by Abe (1978) who found that gold followed by cadmium on rayon, silk and thin cotton resulted in visualising fingermarks on the fabric’s surface and even on the reverse of some of the thinner fabrics, which they suggested was a result of the fingerprint residues penetrating into the fabric. Though there was some success in the use of VMD on fabrics, further research and the employment of VMD operationally was abandoned when it was determined that radioactive sulphur dioxide was more successful, both in the detail visualised and the fact that it did not impact negatively on further forensic testing.

Experiments with radioactive sulphur dioxide were carried out on several un-named smooth tight weave fabrics first by pressing on swatches pinned to boards and then by grabbing swatches wrapped around an arm. These experiments resulted in “characterisation of finger and palm impressions”, though this did not result in “uniform clarity” of ridge detail over the whole grab impression as seen in the joints of the fingers probably due to the hand position and grabbing action used during the deposition onto the fabric (Godsell 1972; Ganson and Godsell 1973). Further tests found that radioactive sulphur dioxide could label and thus visualise marks older than 5 days found indoors, however deterioration of the marks did occur after seven days and if a piece of evidence had been recovered from an outdoor site then it would not recover marks older than 1 day (Godsell 1972; Jones and Clark 1975). The majority of these studies were all carried out on clean, new, unworn fabrics, though Collins, Coles and Stroud (1973) did investigate, using VMD, a corset and a blouse, though the results were not impressive – the corset showed no marks, but did visualise marks from the spring reinforcements, while the blouse showed only fresh marks but not on the section that was left outside overnight in 100 % relative humidity. Thus it was concluded that fabric that has been worn does not stop the visualisation of marks and marks, though it should not have been in contact with the skin (such as underwear), or underneath or in contact with other clothing (such as a shirt worn under a jacket).

Hambley (1972) carried out substantial work on VMD over the course of his PhD determining that single metals had problems during coating – zinc led to spotting, copper and antimony coated the whole surface of the substrate thus leading to the loss of any potential marks. It was discovered that zinc and cadmium were ultimately the best metals to use, but at reduced temperatures, a thin film of gold or silver had to be added prior to the use of zinc or cadmium. The use of these metals on various fabrics was then studied and it was seen that lower gold amounts gave the best level of detail when followed by cadmium and that all the fabrics, with the exception of red nylon, gave good quality marks. The red nylon was an open weave fabric that moved under contact, thus any marks would be distorted during deposition. There was, however, a problem with recording images as detail seen by the eye was not captured by the camera. The issues involved the fibre distorting the ridges or it being difficult to work out which were fine ridges of marks and the weave of the fabric. Therefore work was carried out on determining the best method, including X-ray, infrared, white light and UV illumination to record the marks, but these were all limited or even completely unsuccessful. Overall, Hambley determined that marks could be visualised on fabrics, though there is an effect from the donors, how the marks were deposited, and even what the fabrics were washed with. It was found that detergents break down the fats and greases on the fabric during and after the washing process and this impacts on the fingerprint residues leading to degradation. Thus one week was the time limit for developing fingermarks and this was under ideal conditions. It was concluded that fabrics of a close weave should develop fingermarks and that the deposits penetrated the weave allowing continuous ridge detail to be observed but coarser fabrics may develop discontinuous ridge detail.

Work was also carried out in the 1980s, by Albinson (1984) at the Scientific Research and Development Branch (SRBD), using worn clothing and several different visualisation techniques, including VMD and radioactive sulphur dioxide. The items used were a mixture of old clothing that had been washed and worn for years, as well as new clothing that went through at least six "wash and wear cycles". With the radioactive sulphur dioxide, the results were fabric dependant – polyester cotton had low contrast between the fabric and the marks, with a "high background", this was thought to be due to "body soil" and washing powders. Of the other fabrics tested silk, polyester, nylon and acetate had a "low background" and better contrast between the substrate and the marks. VMD gave similar results – polyester cotton was of lower quality due to the texture of the fabric's surface, which led to metal deposits that were light and patchy. Acetate, nylon and silk all showed good detail and contrast between the fabric and the marks. Both techniques were tested with split marks on day one and day seven and VMD showed more detail on the day one samples, 31 % of the marks were graded 3 or 4 (3 - some ridge detail observed, but most obscured by the fabric weave: 4 – ridge detail and characteristics observed), whereas the remaining splits at day seven only had 10 % graded 3 or 4. With the radioactive sulphur dioxide there was a greater reduction in detail from the one to seven day samples and when directly comparing the two techniques the radioactive sulphur dioxide gave better results – 38 % graded 3 or 4 compared to only 10 % with VMD. Overall, it was felt that finding good identifiable fingermarks on fabric with either technique was "very low" and that a good donor was necessary to lay a mark on a close weave smooth fabric that was kept in a protected environment and processed quickly after the incident.

With regard to fabrics and the suggested use of either radioactive sulphur dioxide or superglue fuming (Bowman 2005) [Figure 1.16], it is CAF that offers the best option. In both cases, the manual states that the fabric needs to be clean, free of nap, with minimal folds or creases caused by handling and have a minimum thread count of three threads per mm of fabric to have any chance of success in visualising a latent mark (Bowman 2005). Radioactive sulphur dioxide is no longer being used operationally (Deacon, P. 2006. pers. comm., 18 September); in fact the CAST (formally known as HOSDB) equipment was put into storage in 2005 (HOSDB 2005b). Therefore, the use of superglue and the previously researched VMD, along with a few other visualisation treatments, will be one of the focuses of latent mark recovery in this study.

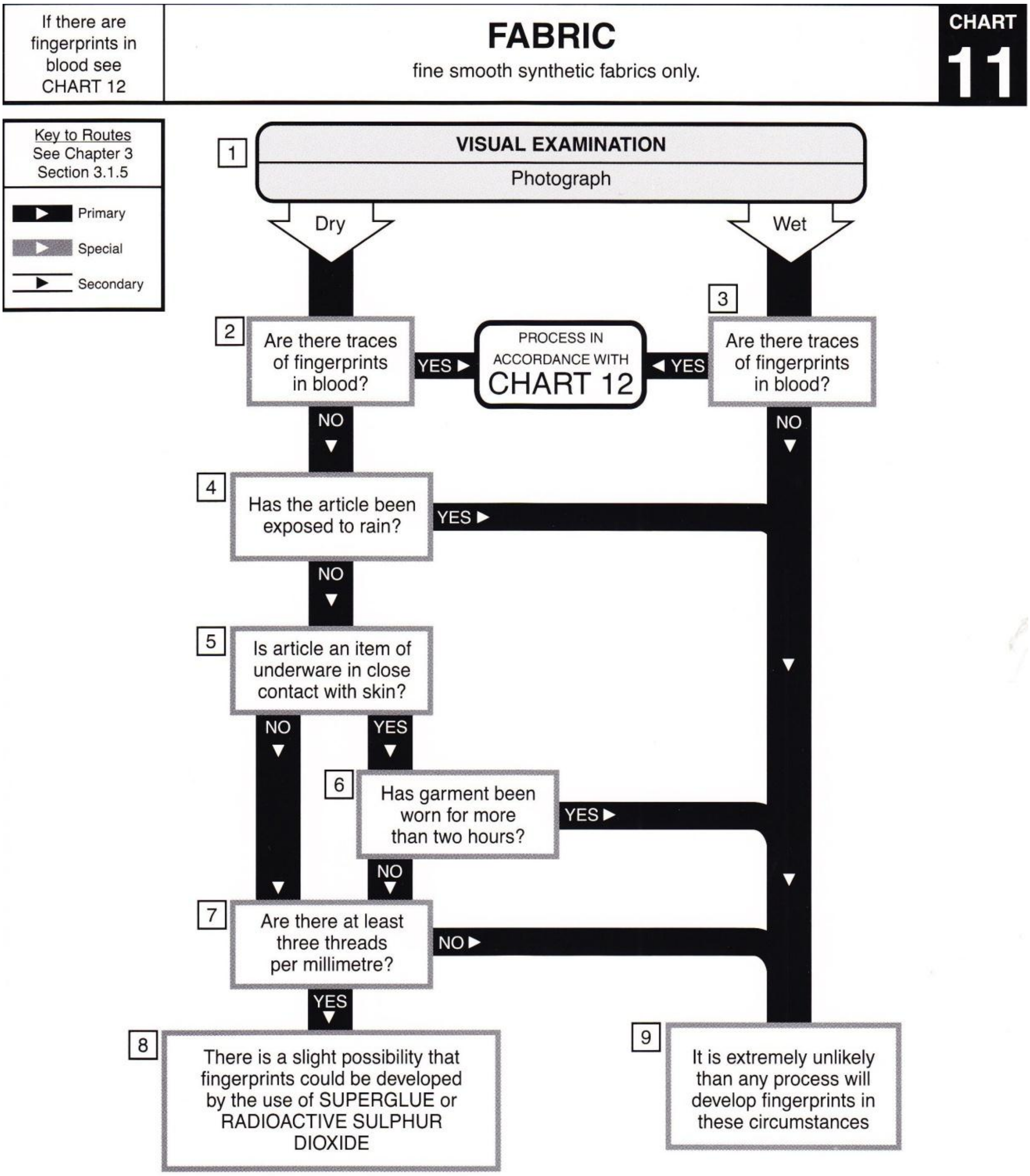


Figure 1.16: Process selection for fabric from the Fingerprint Development Handbook illustrating the considerations that must be taken to determine if it will be possible to visualise fingermarks on fabric and which process to select for developing fingermarks on fabric. Chart 11 Fabric fine smooth synthetic fabrics only (Bowman 2005, p. 11-2).

1.3 Background to Vacuum Metal Deposition (VMD) and Cyanoacrylate Fuming (CAF) techniques used in research

1.3.1 VMD

VMD uses high vacuum and the heating of metals to cause their evaporation and then subsequent coating in thin layers on smooth substrates such as glass and plastics. This is a highly sensitive technique that is effective on older items that have been exposed to extreme conditions, such as water (Bowman 2005). There are several different systems and manufacturers of VMD equipment, though all work in the same manner. The article to be processed is attached to the workholder [Figure 1.18], generally with magnets, and the pressure is lowered to below 3 x 10^{-4} mbar and gold is heated in the filaments [Figure 1.17] for 10 seconds, followed by zinc (at a pressure of ~5 x 10^{-4} mbar) until ridge detail is viewed. This procedure applies in the case of a manually operated VMD system but in automated VMD, times will be pre-set for the zinc heating cycle and as there may not be a window, the zinc deposition cannot be viewed. Generally, gold is deposited first the whole surface of the substrate is coated and penetrates into any fingerprint residues, forming a nucleating layer of agglomerates to which the zinc then adheres to produce a grey coloured coating. This leads to a negative mark where the valleys of the mark are grey in colour as the zinc cannot penetrate the fingerprint residues and can only attach to gold that is not in the fingerprint residues. Thus, the areas that are coated by the fingerprint residues remain the colour of the substrate though there are incidences were the opposite occurs and a positive mark is produced (Lennard 2001; Bowman 2005; Dai et al. 2006) [Figure 1.19]. It has been suggested (Smith 1989) that one reason for this is due to "epitaxial growth" of the crystals of sodium chloride within the fingerprint residues allowing the gold and zinc to bind in the residues, thus causing a reverse of the norm. However, Kent et al. (1976) suggested that this was due to the substrate being processed absorbing the organic components in the fingerprint residues, leaving the solid inorganic salts, which means the gold penetrates the substrate rather than the residues. Another explanation could be the substrate being processed, for example high-density polyethylene is generally negative development whereas low-density polyethylene generally shows positive development (Grant, Springer and Ziv 1996). Therefore, in the case of VMD, the production of a negative mark is considered normal, with the dark valleys and substrate coloured ridges, whereas the reverse of this in the form of a positive mark would be considered unusual. Consideration of this must be taken into account when examining the visualised marks as it may be necessary to reverse the normal negative mark digitally. This is to ensure that the ridges become dark and the valleys are the colour of the substrate, that is the appearance of a mark the examiner will be used to viewing.

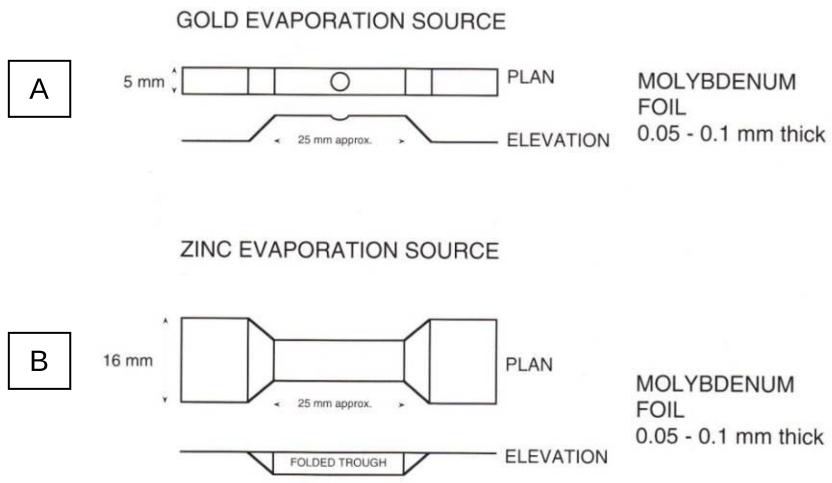


Figure 1.17: Evaporation sources in which the metals (traditionally, A – gold and B – zinc) are held and heated in the VMD chamber during the VMD process (Bowman 2005, p. 17).

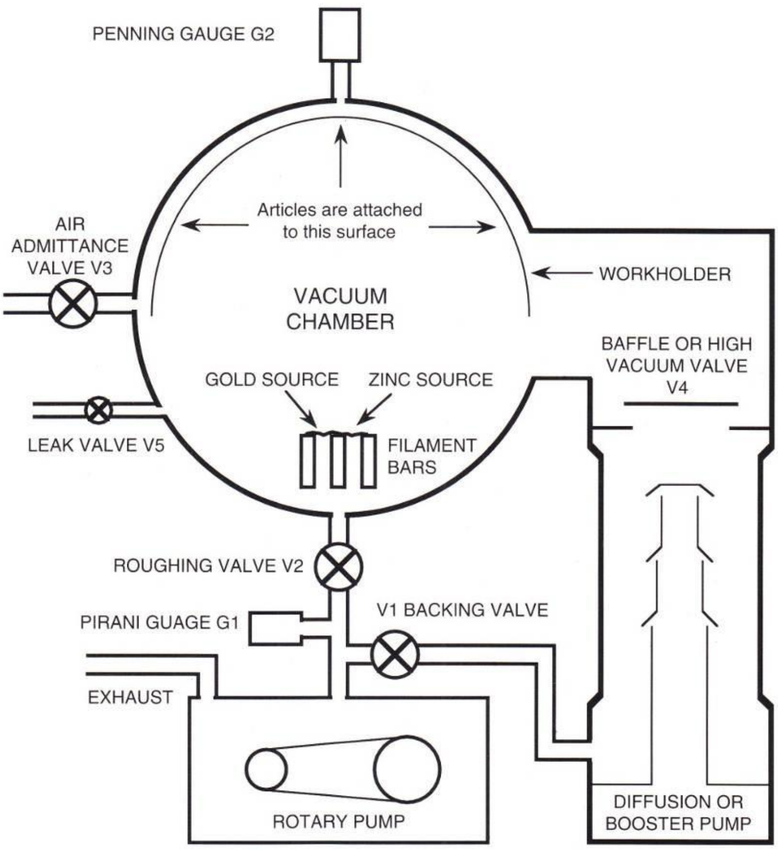


Figure 1.18: A Vacuum Metal Deposition Unit schematic illustrating all the components of the chamber and pumps required for the VMD process (Bowman 2005, p. 11).

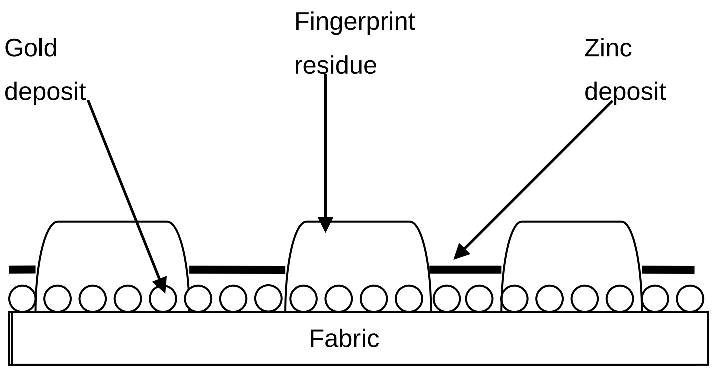


Figure 1.19: VMD deposition of gold and zinc onto fabric and fingerprint residues. Gold covers the whole surface of the substrate and penetrates into the fingerprint residues, while the zinc only attaches to the freely available gold that is not covered by the fingerprint residues (adapted from Philipson and Bleay 2007).

VMD was not designed to detect fingermarks, but to apply metal coatings, such as semiconductors, a process that required the workers to wear gloves to prevent fingermarks from forming on the surface of the items. This led Professor Tolansky to suggest to the Home Office that they use this technique to develop latent marks on paper (Edwards 1976; Kent et al. 1976; Young 1980; Smith 1989). This idea was investigated in France on different types of paper – uncoated, onionskin, glossy and typing paper, to determine which metal types would visualise the most detail and how long these marks would last (Theys et al. 1968). The majority of research determined that gold followed by cadmium was the best sequence, though due to the health and safety issues associated with cadmium it was replaced with zinc (Kent 1981). VMD was also investigated as a method for recovering fingermarks from fabrics. More recently, work has been carried out in Australia on various plastic types and the different "print development regimes", along with selected levels of gold needed prior to deposition of zinc (Yamashita and French 2011). Jones et al. (2001a, 2001b, 2001c) investigated the effect of excess gold during "normal and reverse development" on polyethylene. They also studied the effect of donor, age of mark and polymer type on how latent fingermarks developed on other plastics. Results showed that extra gold could be added to a sample without inhibiting zinc deposition as long as gold, then zinc is added before removal of the sample from the machine the process may be repeated as if it had not been previously processed. This is due to the original gold clusters having been deactivated by the zinc and air forming zinc oxide, therefore not all of the new gold bonds to the original gold clusters (Jones et al. 2001b). It was determined that it was the substrate surface causing the normal and reverse development, due to how the gold film formed on the substrate and therefore how the zinc attached to it (Jones et al. 2001a). This effect of the substrate surface was further investigated (Jones et al. 2001c) and it was concluded that it could be due to the plasticisers and dyes that had been added to the polymers. Thus, it would be advantageous to identify the polymer prior to VMD to help determine the likely number of gold counts that would need to be used. They also determined that the donor and the heaviness of their deposits greatly affected how well marks were developed. Heavy deposits required greater gold counts for development and may only show as empty marks, while lighter deposits need a smaller amount of gold. This is also reflected in the age of a mark and when empty marks occur since as marks age they dry out and become thinner and lighter, whereas empty marks are caused by heavy deposits that cover the whole mark area so the gold becomes buried and not available for the zinc to bind to, so no ridges are visualised. This may be caused by the donor having heavy deposits or by the substrate allowing diffusion of residues, thus filling of the valleys (Jones 2002). These are all factors that need to be considered with the various manmade and natural fabrics, as well as the different donors and the timeline used in this study.

1.3.2 CAF

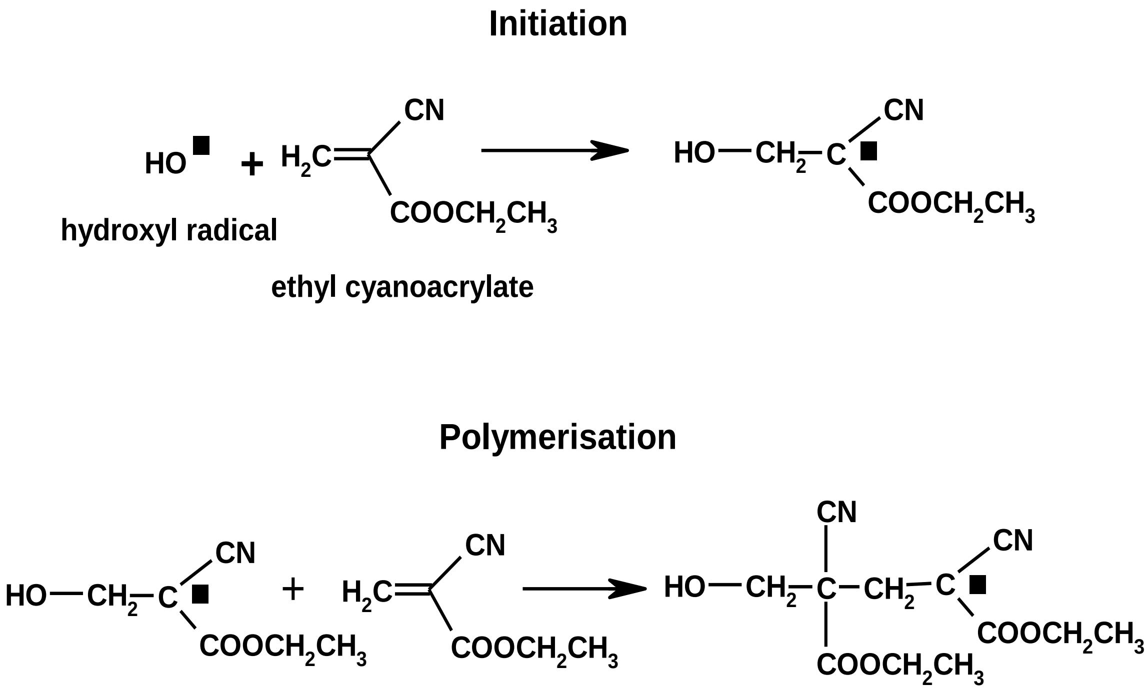


Figure 1.20: Polymerisation reaction for ethyl cyanoacrylate. Initiation by the hydroxyl radical on ethyl cyanoacrylate followed by polymerisation (Bleay et al. 2012).

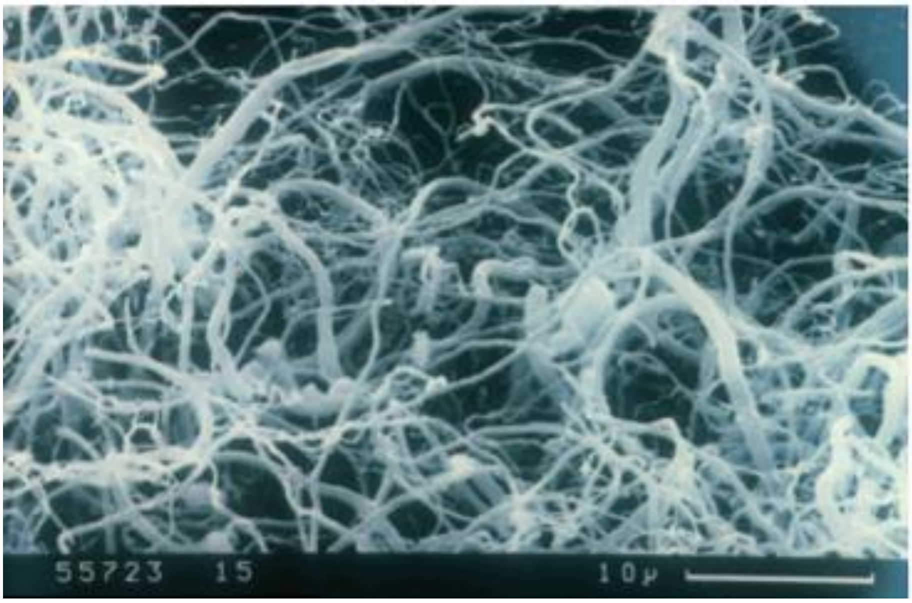


Figure 1.21: Electron micrograph of fibrous appearance of cyanoacrylate developed at high humidity (Bleay et al. 2012).

Ethyl cyanoacrylate or "superglue" was developed as an adhesive in the 1950s and has even been used in the 1960s during the Vietnam War to close wounds. Then in the 1970s researchers in both Britain and Japan discovered they could develop latent fingermarks using the fumes from the glue. This technique is used on just about all non-porous substrates, such as glass, plastics and metals as well as rough substrates, such as vehicle cowlings (Lennard 2001; Bowman 2005; Yamashita and French 2011; Bleay et al. 2012). The polymerisation reaction [Figure 1.20] is not fully understood however it is thought that the vapours interact with the water and other constituents within the marks to polymerise into a white residue producing deposits that appear long and fibrous under scanning electron microscopy (SEM) [Figure 1.21] (Bandey and Kent 2003). Interestingly, for successful polymerisation to occur there is a need for an 80 % relative humidity because of chlorides present taking up water (recommended by Kent in his 1981 paper and confirmed in 2011 by Paine et al.). However, some researchers believe it is the amino acids and proteins in the residues to which the cyanoacrylate (CA) binds and polymerises (Houck and Siegel 2006; Anon 2013) but this was disproved by the Czekanski, Fasola and Allison 2006 study when the solid amino acids by themselves did not lead to the CA adhering or polymer formation. They did find that hydrocarbons "fumed first" and considering that these can be detected on the skin's surface they could in some way be part of the polymerisation reaction. The Wargacki, Lewis and Dadmun paper (2007) suggested that the reaction might be caused by lactate and alanine that are found in eccrine sweat residues, as they are capable of initiating the process. This polymerisation will happen at room temperature, though it is accelerated by heat; thus CAF cabinets are heated to 120 °C (Bowman 2005). Care must be taken not to heat the glue too high as it has been found that at temperatures higher than 220 °C hydrogen cyanide gas can be produced, which is hazardous to health (Stokes and Brennan 1995). The white polymer that is produced from a fingermark is visible on darker substrates, however on lighter coloured substrates it sometimes needs to be further enhanced by the use of fluorescent dyes, such as basic yellow 40 (BY40) which could then by viewed and recorded under laser or Crime lites (Bowman 2005).

BY40 was used originally as a textile dye and, as the name suggests, will dye the CAF polymer a yellow colour. However to fully see and record the ridge detail visualised by the CAF and BY40 it needs to be viewed under a light source, such as a Quaser (excitation filter – cut on 385 nm and cut off 469 nm, viewing filter – cut on 476 nm) or Crime lite (Blue 420-470 nm, goggles GG495 and filter yellow 476 nm). The items that have been treated with CAF are generally submerged in BY40 for one minute to allow the dye to adhere to the CA polymer and then rinsed with running water to remove any excess dye from the surface of the substrate. BY40 is also considered safer that some of the other dyes that have been previously utilised, as none of the ingredients used in its manufacture are carcinogenic and are listed as having low toxicity (Wilkinson 1996) and as a result it is the preferred operational dye in the UK for use after CAF. The reason why BY40 is used to enhance the CA polymer is that it is able to absorb the light emitted by either the Quaser or Crime lites and then emit some of this light at a different but longer wavelength and therefore a different colour. The molecules on the substrate surface will absorb the light shone on it and in doing so it rises to a higher energy level then drops back to a lower level or ground state when it releases energy in the form of fluorescence. The colour of the light observed is different from the light shone on the substrate’s surface and is said to be “red-shifted”. The difference of the excitation light and the emitted light is termed the “Stokes shift”. To allow this new colour to be seen and then photographed filters and goggles must be used to remove the reflected light that is not absorbed and allow the fluorescent light to be transmitted. The correct wavelength of light or excitation band must be used or the dye, in this case, BY40 will not fluoresce and the fingermark will not be distinguished from the background substrate. This wavelength of light can be produced by a Blue Crime light (420-470 nm) or Quaser (350-469 nm) and the correct viewing filter, camera filters and goggles must be used to allow the operator to view and record any fingermarks that are visualised (Bowman 2005; Yamashita and French 2011).

1.3.3 VMD versus CAF and sequential treatment

Several studies have been carried out comparing VMD and CAF for their sensitivity in visualising fingermarks but the reported results were mixed with some indicating that VMD was better than CAF, while others showed little or no difference. For example, in the study by Lennard et al. [1992] it was found that both VMD and CAF showed the same levels of sensitivity on 3 year old glass and polythene samples. However, CAF followed by VMD did at times increase the detail especially on plastic credit cards, but VMD followed by CAF did not enhance the detail observed. Misner (1992, 1993) found that VMD detected around 15 % more marks than CAF and Masters and DeHaan (1996) observed that marks under two months old gave the same level of detail with both VMD and CAF (86 %), while with marks over 24 months old VMD was more successful – 84 % compared to 60 %.

Overall, VMD is considered a more sensitive technique than CAF (Kent 1990; Misner 1992; Masters and DeHaan 1996) when it comes to fingermarks that have been exposed to adverse conditions, such as rain or if the fingermarks are old (Batey et al. 1998). However, CAF is less expensive, is available to most Police departments and researchers, as well as being an easier technique to implement.

CAF/VMD sequential treatment has been carried out on other substrates, such as milk cartons, cling-film and polymer banknotes. The milk carton went through CAF and fluorescent staining, which visualised limited ridge detail. Further treatment with VMD produced three identifiable marks, which in turn led to an identification of a suspect, a guilty plea and the suspect waiving his right to trial (Murphy 1991). With the cling-film, it was determined that sequential use of VMD with gold + zinc followed by silver gave ridge detail in empty marks, whereas silver then gold + zinc "gave no improvement in ridge definition". In addition, silver deposition could be carried out before or after CAF, but neither gave much improvement, while gold + zinc should be carried out before CAF "to maximise the number of marks developed". This in turn led to a suggested sequential order of gold + zinc VMD, silver VMD, then CAF (Philipson and Bleay 2007). With polymer banknotes, it was determined that VMD after CAF required less gold and led to marks of better quality. However, the use of stains before CAF or VMD led to worse detail as it was believed that the fingerprint residues were "washed away", thus there was less mark to visualise. Also, CAF and BY40 followed by VMD led to zinc being deposited across the whole surface of the banknotes, and even though the deposits were fainter on the ridges it made them harder to see. Even repeated staining did not increase the contrast between the substrate and ridges, therefore this order of visualisation was not deemed to be "an acceptable option" (Jones 2002). However earlier work on polyvinyl chloride (PVC) and polyethylene terephthalate (PET) plastics determined that marks developed with sequential CAF then VMD treatment would normally result in empty marks. It was suggested that CAF must be affecting how the gold layer forms or deposits on the substrate (Jones 2001c). Jones, Downham and Sears (2012) took the study of VMD and CAF to the nano level by examining the residues and deposits with scanning electron microscopy (SEM). Here they found that the CA was concentrated around the pores on the ridges and that once VMD was applied it led to additional visualisation as the metal deposits covered areas not coated by the CA. The metal did adhere to the CA polymer, but also to areas with no CA, thus the ridged detail was enhanced, though the areas without the CA were lighter. Normally, in the UK, CAF followed by VMD is useful in increasing the clarity of ridges, especially on plastic packing materials, however some police forces still prefer to use VMD first (Downham 2011). With this in mind this study will also investigate whether VMD followed by CAF or CAF then VMD is the more effective sequential treatment on fabrics.

As previously discussed, fabric is a difficult substrate on which to visualise fingermarks, however as crimes, such as assault, kidnapping and robberies can involve fabrics, textiles and clothing it would be highly advantageous to be able to visualise marks, marks and to identify areas from which to collect DNA.

Therefore, the main aims of the research were to determine:

- whether latent marks can be visualised on fabric;
- the most effective technique for acquiring marks from fabrics;
- the factors which contribute to the acquisition of marks from fabrics;
- if the type of mark can give an indication of the sequence of events in an incident/crime;
- if DNA can be collected from the visualised areas;
- if alternative visualisation techniques could be employed.

2. EXPERIMENTAL

2.1 Fabrics

All of the fabric types chosen for this study are used in the manufacture of common clothing and all complied with the Home Office requirement of a minimum of three threads per mm.

Cotton (100 %, white and dark blue, 3 threads per mm)
Polycotton (60 % cotton and 40 % polyester, white and black, 3 threads per mm)
Polyester (100 %, white and black, 4 threads per mm)
Nylon (100 %, white, 3 threads per mm)
Nylon-Lycra (80 % nylon and 20 % Lycra, white, 4 threads per mm)
Satin (100 % viscose, white and black, 4 threads per mm)
Silk (100 % Crepe de Chine, heavy white, 6 threads per mm)
Viscose rayon (100 % regenerated cellulose, white, 4 threads per mm)
Linen (100 %, white, 3 threads per mm)

2.2 Donors

The donors used in this study were a mix of males and females who ranged in age from 35 to 60 years old and had varying potentials to leave fingermark deposits. Originally, there were 20 donors, however five dropped out of the study at various points (donor four, fourteen, seventeen, eighteen, and nineteen) therefore their data was removed from the final analysis.

Prior to collection, the donors had not washed their hands or applied cosmetics/hand creams for at least 30 minutes and had not been loaded with extra sebaceous deposits, therefore the deposits left were "natural" and contained only the deposits normally found on the donors' hands. The donors were asked to rub their hands together prior to deposition, to ensure an even distribution of residues over the surface of the skin on their hands and fingers. In chapter 7, where other researcher's work is discussed, some of these donors used a loaded method of deposition, as detailed in section 7.6. The loaded method of deposition involves the donor wiping their fingers and palms over their forehead, nose and/or behind their ears to add extra sebaceous and sweat secretions. Again, the donors would then rub their hands together to evenly spread these additional residues over their hands, prior to deposition.

All donors had been previously graded on paper substrates thus indicating their relative ability to leave marks on these substrates. It is noteworthy that this did not always correspond to the results on fabric in that a donor may have been good on paper but not on fabric and vice versa. Also, some depositions were carried out differently from above depending on the visualisation process being used and details for the specific methodology can be found in individual sections.

The types of donations can be classified as:

(1) Grabs – the fabric swatch was placed over the arm of the collector, who was wearing a lab coat. The donor then grabbed the arm and swatch with reasonable force for approximately 10 seconds to simulate the action of an assault. The consistency of pressure applied was determined by the researcher who was being grabbed. Grabs were utilised in this study as they were closer to an action that may occur during an assault and thus a more realistic scenario. The use of a balance was deemed inconsistent and that apparatus, such as "the fingerprint sampler" design by Sarah Fieldhouse (2011) was not practicable for this type of deposition.

(2) Pushes – this process was used by some of the student researchers and involved the donors pressing down, for approximately 10 seconds on the fabric swatch, either onto a flat surface, such as a table, or onto the collector's lab coat covered arm, again.

(3) Split grabs - the fabric swatch was placed over the arm of the collector who was wearing a lab coat and the donor then grabbed the arm and swatch for approximately 10 seconds making sure that 2 fingers were on each side of the middle on the swatch. The swatch was then cut in half, so that one portion could be exposed to the condition under study and the other half acted as a control.

(4) Split depletions – a collection grid with either three or four columns of 5 cut out sections was placed over the fabric swatch and a mark was placed at the top and bottom of each cut out to show were the middle of each mark was. The donor then pressed the same single finger into each cut out section in the column thus leaving latent marks with fewer residues as they worked down each column. The marks were then cut down the middle to allow the comparison of different techniques on the same fingermark set. The number of sets of columns, three or four, was dependent on how many techniques were being compared.

2.2.1 Donor grading

Poor - Produced little or no target area, nor detail in palm and fingertips.
Medium - Produced a target area, leaving some palmar flexion detail and some ridge detail in fingertips.
Good - Produced a target area, leaving palmar flexion crease detail and excellent to good ridge detail in fingertips.

The assigned grade ranges were based on the level of detail visualised on the samples. This was based on the grades assigned to the samples grades (see section 2.4), these values for each fabric type were added together and divided by the number of days (10) to determine the average value. This led to grading ranges of 0 – 1.3 for poor; 1.4 – 1.5 for medium to poor, 1.6 – 1.9 for medium, 2 – 2.3 for good to medium and 2.4 and higher for good. The intermediate grades of medium to poor and good to medium were included to take into account that there could be a mixture of high and low grades within the set. Thus, the range of grades as well as the target areas in the samples were then taken into account when assigning the overall grade value ranges.

As previously stated all donors prior to their inclusion in the study were tested on paper to determine their propensity to leave fingermarks. This however was only an indication as a donor could have been rated as good and leave excellent fingermarks on one substrate only to be considered a poor donor on another substrate as little or no detail was left.

2.3 Storage

All swatches were stored in the dark, at room temperature in labelled plastic wallets for 1, 2, 3, 4, 5, 6, 7, 14, 21 or 28 days or 1, 3, 7 or 28 days, dependent on the study and were then processed at the relevant time.

2.4 Grading of marks

The grading of the marks was based on the Home Office (CAST) system (Sears et al. 2011):

(0) No development – negative, no visible or recognisable marks on fabric.
(1) “Empty” marks - could see where the donor had touched the fabric but no ridge detail on fingertips or palm.

(2) Fair – Full pattern and ridge flow on 1 or 2 fingers or approximately 1/3 partial detail on all the fingers and/or palmar flexion creases visible, but not enough detail for identification.

(3) Good - ridge characteristics (Galton details) visible on at least 3 fingers or approximately 1/3 to 2/3 partial detail on all fingermarks.

(4) Excellent - good ridge detail on all 5 fingertips and palm with visible pores, ridge edge detail and ridge flow.

2.5 Vacuum metal deposition (VMD) materials and methods

2.5.1 <u>Gold + zinc</u>

The fabric types used in this study were cotton, nylon, polyester and polycotton and were all white in colour. The fabrics were prepared for deposit collection by cutting 23 cm x 16 cm sized samples, which were labelled with the fabric type, hand position (F – fingers, P – palm), donor number and process day. The deposition collection was carried out by the fabric swatch being laid on the collector's arm and the donor "grabbing" the sample firmly for 10 seconds. After acquisition, the samples were kept in plastic wallets, as described in section 2.3 above.

The VMD equipment used in this study was an Edwards 24" Metal Deposition Unit, manufactured by Mason Vactron Ltd UK and was operated manually as described in the Home Office Scientific Development Branch documentation (Bowman 2009). The samples were placed in the chamber and attached to the holder using magnets around the sample's edge. Gold wire (0.25 mm in diameter 99 %, Knight and Day) was cut to approximately 5 mm length (0.002 g) and was placed in the centre filament and zinc pieces (1 g) were added to the other two filaments. The chamber door was closed and the pressure reduced to 4×10^{-1} mbar (roughing cycle) before switching to the high vacuum cycle. The chamber pressure was reduced to 3×10^{-4} mbar and the gold filament current was switched on to allow the gold to evaporate for about 5 seconds. The zinc filament was then turned on until sufficient zinc was deposited and fingermark detail could be seen on the sample as well as the paper test mark, which was placed next to the sample to ensure the process was working correctly. This was all directly observed throughout the deposition process. The VMD chamber was then brought back up to atmospheric pressure, the sample removed, labelled with a scale containing details of the fabric type, donor and test day, and then photographed. The visualised marks were then graded.

2.5.2 Silver

The fabrics (specimen size - 23 cm x 16 cm) which were investigated were black polycotton (60 % cotton and 40 % polyester mix), black polyester, black satin and dark blue cotton. They all had four threads per mm of material and were hand washed prior to use using detergent powder (ASDA 2 in 1 Moonflower and Ylang Ylang biological washing tablets) to remove any potential contaminants. Once prepared, each fabric specimen was stored in a plastic wallet labelled with the donor number and the day on which the marks were to be collected.

The left hand grab mark was acquired by placing the fabric over the collector's arm and the donor grabbed it firmly for 10 seconds. The right hand press mark was acquired by laying the fabric on the collector's arm and having the donors press firmly for 10 seconds. After collection, the specimen was returned to its wallet as described in section 2.3, and then treated with silver VMD (Ag-VMD). All marks were "natural", thus no extra residues or cosmetics were added and the donors would not have washed their hands for approximately 30 minutes prior to deposition. This in turn meant only one fabric type was collected at a time and if more than one specimen was collected per day a time period of at least 1 hour was ensured to allow the donor's secretions to be replenished.

An Edwards 24" metal deposition machine (Mason Vactron Ltd, UK) was used for the treatment of specimens. The silver wire (0.5 mm in diameter 99 %; Sigma-Aldrich UK) was cut to approximately 5 mm lengths and 3 pieces (30 mg in total) placed in the central evaporation boat within the VMD chamber (HOSDB 2005a). The fabric specimen was placed in the chamber and it was evacuated to a pressure of $3x10^{-1}$ mbar using rotary pumps then switched to diffusion pumping to obtain a high vacuum of about $4x10^{-4}$ mbar, at which point the current to the boat containing the silver was switched on and increased until the silver evaporated (about 5 seconds). Test marks on paper were placed next to the samples in the VMD chamber in order to confirm that the process was working properly. After treatment, the VMD chamber was brought back to atmospheric pressure, the specimen removed, labelled with a scale-ruler detailing the fabric type, donor, test day, then photographed and all visualised marks were graded.

The VMD equipment oil levels were regularly checked by the Scottish Police Authority (SPA) staff to ensure that the equipment was running optimally. The equipment was cleaned after each use by the researcher to remove any metal deposits from the interior surfaces and the viewing windows in order to reduce the chances of cross-contamination by use of MicroSol on the interior surfaces, while the glass viewing windows were cleaned after each use with a 10 % acetic acid solution, followed by water and then oil (Silkair VG22 general purpose airline oil). The interior was also relined with aluminium foil, thus ensuring there was no build-up of metals on the glass or interior surfaces which could lead to the heated VMD metal preferentially attaching to the previous metal build-up rather than the current sample being treated. An external contractor (Applied Vacuum Engineering Ltd.) was also employed to service the equipment - testing all the pumping systems, vacuum capabilities thus determining that it was operating at optimum standards.

2.6 Cyanoacrylate (CAF)

2.6.1 Benchtop superglue fuming chamber

The Electronic Services (London) unit consisting of a low-profile flat plinth housing a humidifier, glue heater, circulation fan, purge-unit (containing 1.25 Kg of activated carbon granules within a nylon bag) and control panel was utilised.

Prior to the start of the trials the temperature of the hotplate was determined by the use of a digital thermocouple (RS 206-3738) and the humidity by means of a humidity meter (Fluke 971) in order to determine that they were at the correct operational needs of 120 °C and a relative humidity of 80 %.

The cabinet was also profiled to determine whether the glue vapour was evenly distributed throughout the cabinet or whether there were areas of higher or lower concentrations of glue vapours. This was carried out by placing pieces of acetate loaded with a single latent fingermark at different positions in the cabinet and comparing the quality of mark developed. Using this technique, it was determined that the cabinet did in fact have an even distribution of vapours and therefore samples could be placed in all areas of the cabinet.

After each run the interior of the cabinet was washed with water and detergent (Tesco washing up liquid) to remove any polymer that had formed on the surfaces and a soft sponge was used to prevent scratches from forming. This is done to prevent preferential attraction of the glue vapours to scratches and polymer on the cabinet interior rather than the sample being processed.

The samples were hung from the rails leaving gaps to allow air to circulate and ensure a uniform humidity and dispersion of cyanoacrylate (CA) fumes within the chamber. The water reservoir was filled with distilled water and CA (approximately 0.5 g Superglue, CSI Ltd.) was placed in an aluminium foil tray on the glue heater, making sure the bottom of the tray was in good contact with the heater. The glass lid was then placed over the base unit, checking that all the seals were covered. Once each cycle (humidity – 5 minutes, glue – 12 minutes and purge – 20 minutes) was completed, the samples were removed and enhanced by dipping for 1 minute in basic yellow 40 (2 g BY40 in 1000 mL ethanol) then rinsing with water, and viewing the visualised impressions under Quaser light (350-469 nm) or Crime lite (Blue 420-470 nm). The visualised marks were then photographed using either the Quaser or a Nikon D40 digital camera with a yellow 476 nm filter and then graded.

2.6.2 Scottish Police Authority Forensic Services (SPAFS) CAF cabinets

Some samples were processed using either an MVC3000 or MVC5000 cabinet located at the SPAFS Dundee labs. Both cabinets were used in the automated mode and had also been profiled by placing acetate pieces with a single print on them in 9 separate areas throughout the cabinet. This determined that each of the cabinets worked evenly throughout, so there were no issues as to where samples had to be placed for processing.

The CAF cabinets were regularly tested, by means of a thermocouple (RS 206-3738) and humidity meter (Fluke 971) as well as being regularly cleaned by the researcher and the Scottish Police Authority (SPA) staff to determine the equipment was running optimally. The cleaning was necessary to prevent a build up of cyanoacrylate polymer on the cabinet's surfaces, which could lead to preferential attachment of the cyanoacrylate fumes to this polymer rather than the items being processed. The glass surfaces were cleaned with a dilute washing up detergent/water solution. The cabinets were also regularly tested for DNA contamination and cleaned with MicroSol. This is important if the samples were to be sequentially tested for DNA after CAF processing as DNA from previous samples could lead to cross-contamination. An external contractor (foster+freeman) was also employed to service the equipment - testing all the systems, determining that the cabinets were operating at optimum humidity and heating standards, as well as ensuring that the filters removed all the glue vapours.

The samples were hung in the CA cabinet and ethyl cyanoacrylate (Cyanobloom, foster+freeman; 2 g for the MVC3000 or 4 g for the MVC 5000) was added to the aluminium foil dish in the heater. A standard 45-minute cycle with relative humidity of 80 % and temperature of 120 °C (15 minute humidity cycle, 15 minute superglue cycle and 20 minute purge cycle for the MVC 3000 and 40 minute purge cycle for the MVC 5000) was used to visualise the samples. Once processed, the samples were then enhanced with BY40 and recorded as described above.

2.7 Quaser

The Quaser (2000/30 Mason Vactron, UK) was fitted with a 300 Watt Xenon arc lamp with an output range of 350 – 600 nm. The excitation filter wavebands were between 340 and 600 nm, while the six viewing filters ranged between 593 nm and 476 nm and the filter selected was dependent on which chemical visualisation process had been used. The Quaser camera lower filter was set with IR Block on and the wavelength was adjusted using the upper filter between 415 nm and 593 nm.

Samples were placed on the sample tray under the camera lens on the worktable and were then photographed under the appropriate wavelength of light, camera filter and viewing filter.

CAF – wavelength (355-469 nm), camera and viewing filter (476 nm).

DFO – wavelength (473-548 nm), camera and viewing filter (497 nm).

SPR – white light and no camera or viewing filter.

The laser output of the Quaser was tested regularly to confirm it was working optimally. This was done by an external technician during the annual service using a foster+freeman meter and by staff on a monthly basis by use of a camera lens metering (Nikon D300) to view a BY40 stained CAF fingermark, using the same exposure time used at the annual service. If this exposure time increased, then the Quaser output was deemed not to be at its optimum and the technician was called to repair it.

2.8 Crime lites

The Crime lites (foster+freeman, UK) consist of six torches which range in wavelengths (350 nm – 700 nm, UV to white light), along with goggles and camera filters to be used with each different torch. This study utilised different Crime lites to view latent marks visualised with CAF, DFO and the fluorescent fingerprint powder.

CAF – wavelength (blue 420-470 nm), goggles (yellow 476 nm) and camera filter (yellow 476 nm).

DFO – wavelength (green 500-560 nm), goggles (orange 549 nm) and viewing filter (orange 549 nm).

Fluorescent fingerprint powder – wavelength (blue 420-470 nm), goggles (yellow goggles 476 nm) and camera filter (yellow 476 nm).

The appropriate Crime lite for each sample type was mounted onto a small retort stand then shone onto the whole sample surface to visualise any marks. This set-up allowed the researcher to have their hands free to manipulate the sample and camera with ease. The Crime lites were only used for a half hour at a time before the batteries were changed for fully charged batteries thus preventing the battery from becoming low and therefore not illuminating the sample at the full capacity.

2.9 Sputter coater

The fabric swatches (40 x 40 mm) of linen, nylon, polycotton, cotton, black satin, white satin, nylon-Lycra and polyester were each planted with a single natural latent mark and the swatches were left for the desired time period (one hour and 3 days). Each fabric was treated using an appropriate metal target (nickel, copper or aluminium, diameter 55 mm and width 0.5 mm).

The samples were placed one at a time in the sputter coater platform (SEM coating unit PS3) and secured via the stage pin, and then the unit was evacuated. Once the correct vacuum was achieved, the ready light illuminated, the test button was depressed to determine the deposition current, the start button was set to 30 seconds and the deposition commenced. This was continued for approximately 5 minutes in 30 seconds time-periods, with a viewing after each coating, to ascertain if any marks were visualised. To view the sample after each 30 second time-period, the chamber was returned to atmospheric pressure and any marks or deposits noted up to the a maximum of 5 minutes. The samples were all photographed with a Nikon D40 camera and any detail recorded.

The vacuum used ranged from $1 \times 10^{-1} – 3 \times 10^{-1}$ mbar, with a current of 8 – 50 mA depending on the metal target used and fabric being processed.

2.10 Sonication

Samples were sonicated using a 20 kHz Misonix Ultrasonic Liquid Processor (model S-4000-010) with an output power of 600 W and fitted with a titanium probe with tip area of 1.17 cm^2 [Figure 2.1]. The amplitude was set at 35 %, with no pulsing and the location of the probe tip was maintained at 20 mm from the bottom of the reactor vessel (400 mL beaker). Due to heat being produced by sonication of the solution, the reaction beaker was placed in a salt/ice/water bath (15 g salt /~1500 g ice/400 mL water) to aid cooling.

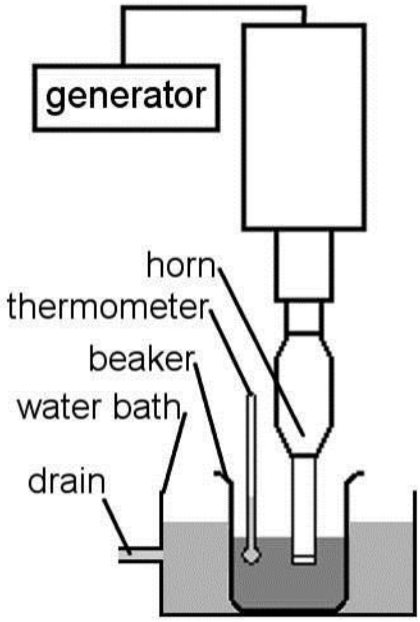


Figure 2.1: Sonication equipment set-up, showing the water bath, the reaction vessel and the ultrasonic probe. (Reproduced with permission from Milne, project work 2012).

2.11 Preparation of carbon particles

2.11.1 From Glucose/hydrochloric acid (HCl)

The preparation of carbon nanoparticles was attempted using an aqueous glucose solution as starting material according to the experimental methodology of Li et al. (2011). Glucose (18.0 g) was dissolved in distilled water (100 mL) in a 250 mL beaker and HCl (100 mL; 36 % wt %) was added. The beaker was partially immersed in a salt/ice bath and sonicated for 6 hours at 20 kHz. The excess water was evaporated in an oven (70 ºC) overnight (10 hours) and a portion of the resulting paste (1 g) was removed and dissolved in distilled water (100 mL), centrifuged (2 minutes), and filtered using a 0.22 μm filter. This solution was then examined, neat and as samples ranging from a 1:1 dilution with water up to a 1:10 dilution, using a spectrofluorophotometer and a fluorescence microscope.

2.11.2 From glucose/sodium hydroxide (NaOH) solution

Glucose (18 g) was dissolved in distilled water (100 mL), to which NaOH (100 mL of 1 mol/L) was added and this was sonicated for 6 hours at an amplitude of 35 %

and no pulsing. The solution was then adjusted to pH 7 with the addition of HCl and then ethanol (100 mL) was added dropwise while the solution was under constant stirring. Magnesium sulfate ($MgSO_4$, 24 g) was added with stirring for 20 minutes, then stored for 24 hours at room temperature before centrifuging (2 minutes) and filtering (0.22 µm). The resulting solutions were stored in large centrifuge tubes and examined neat and as 1:1 to 1:10 dilutions with distilled water, using the spectrofluorophotometer and a fluorescence microscope.

2.11.3 From coffee

Coffee grounds (1 g) were added to distilled water (100 mL) and sonicated for 1 hour at 35 % amplitude and no pulsing. The solution was centrifuged for 2 minutes, filtered using a 0.22 µm filter and then stored before applying to latent marks on various substrates (glass, paper and fabric) to determine the effectiveness in visualising latent fingermarks. These marks were then viewed using the Quaser.

2.11.4 From activated carbon cloth

Activated carbon cloth (2 g) was cut into small pieces, suspended in distilled water (200 mL) and sonicated for 6 hours at an amplitude of 35 %. A sample (10 mL) was removed every hour, centrifuged (2 minutes), passed through a 0.22 µm filter, and then stored in centrifuge tubes. Each sample was then viewed using the spectrofluorophotometer and a fluorescence microscope.

2.12 Characterisation of carbon particles

2.12.1 Spectrofluorophotometer

A spectrofluorophotometer (Shimadzu RF-1501) was used to examine the carbon particles produced above for any evidence of fluorescence. Each solution was placed in quartz cuvettes in the spectrofluorophotometer and the spectrum recorded using the excitation range from 350 to 850 nm, increasing at 50 nm increments. Additionally, the colours emitted were noted and photographs taken.

2.12.2 Fluorescence microscopy

The microscope (Leica DMR Qwin colour) fitted with a camera (Sony EXwave HAD DSP 3CCD colour video camera) was used to examine the particles produced as described above. A thin film of an aqueous suspension of carbon particles was applied to glass slides and allowed to dry at room temperature. The slides were viewed with different light filters (1H, 2H, 3H and 4H), at both the x50 and x400 magnifications and images were recorded.

1H (Filter cube A) – UV excitation range and excitation filter (340 – 380 nm).

2H (Filter cube D) – UV/violet excitation range and excitation filter (355 – 425 nm).

3H (Filter cube I3) – blue excitation range and excitation filter (450 – 490 nm).

4H (Filter cube N2.1) – green excitation range and excitation filter (515 – 560 nm).

2.13 Examination of the carbon particles for visualisation of latent fingermarks

2.13.1 Visualisation with Quaser

In order to allow the solutions to be more easily applied to the test substrates, AEROSOL OT detergent (0.075 mL for every 50 mL of solution) was added to all the solutions prepared above. Loaded marks were placed 1 h previously on glass microscope slides, paper (recycled and white) and fabric swatches and the solutions were applied by pouring the solution directly over the substrate, dipping the substrate into the solution, and/or painting the solution onto the substrate with a soft haired brush. The samples were viewed and photographed under all the Quaser wavelengths using the appropriate filters in an attempt to determine which, if any, were suitable for the visualisation of latent fingermarks.

2.13.2 Visualisation with the fluorescent microscope

All the solutions were applied by pouring, dipping and/or painting onto glass microscope slides containing a loaded mark deposited 1 h previously, then viewed at x50 and x400 magnifications with different cube filters (1H, 2H, 3H and 4H) and images were recorded.

2.14 Studies on the effect of water on samples visualised with VMD and CAF

2.14.1 The effect of moisture on the visualisation of latent marks

The fabric swatches (linen, nylon-Lycra, nylon, white satin and black satin) were planted with natural marks and then cut in half to split the planted marks. One-half was stored as a control and the other half treated with water.

This study used three donors, who were previously determined as good, medium and poor from previous fabric studies. The donors placed a natural grab mark on each of the fabrics for each of the timelines (1, 3, 7, 14 and 28 days) and conditions (dew, moderate rain and heavy rain). These were then split in half and stored in plastic wallets until they had reached the required age.

A spray bottle was filled with distilled water and the fabric swatches were sprayed, individually, with varying amounts of water* to simulate different conditions. The swatches were then allowed to dry at room temperature on a paper towel then stored in plastic wallets for an appropriate amount of time before being processing with either VMD or CAF. The samples (controls and water treated) were then graded and photographed with the Nikon D40 camera (using the yellow 476 nm filter and blue 420 – 470 nm Crime lite in the case of the CAF specimens).

*Water levels:

- dew – one full spray (approximately 1 mL of distilled water) which led to the specimen having a layer of water drops on the fabric surface;
- moderate rain fall – 5 full sprays (approximately 5 mL of distilled water) which produced small areas of water soaking into and through the fabric;
- heavy rain fall – 15 full sprays (approximately 15 mL of distilled water) which completely soaked the sample from the front to the back surface.

2.14.2 Hydrophobicity and hydrophilicity testing

In an attempt to determine the relative hydrophilicity or hydrophobicity of the fabrics (polycotton, nylon-Lycra, nylon, linen, silk, satin, polyester, cotton and rayon, all white in colour as well as black satin) each was cut into 6 x 6 cm sized swatches and weighed on an analytical balance to four decimal places. The samples were then each separately submerged in distilled water (100 mL) for 1 minute, removed, shaken to remove excess water, and reweighed. This absorption of water was repeated 3 times and the average weight gain determined. The swatches were then allowed to dry, then stored in plastic wallets, and reweighed at 1, 3, 7, 14 and 28 day intervals. In order to determine each fabric's starting weight, wet weight and dry weight over a 28 day period.

The intrinsic absorbency value was calculated by dividing the water volume by the weight of the fabric swatch. The volume of water was calculated by the subtracting the dry weight of the fabric from the wet weight in grams and then converting to volume, assuming the density of the water was 1 g/mL. With the weight of each fabric calculated from the average of the dry weights (starting weight, weight after drying; weights at day 1, 3, 7, 14 and 28).

This test is based on that used in the "Determination of Absorbency and Rate of Absorbency of Wipers" (Texwipe 2011).

2.15 Visualisation of latent fingermarks using chemical processes

Each fabric (nylon, nylon-Lycra, polyester, silk, polycotton and satin - all white in colour) was cut into 23 x 16 cm sized swatches. The following studies used three donors, who were previously determined as good, medium and poor from previous fabric studies. The donors placed a depletion series of natural marks on each of the fabrics for each of the timelines (1, 3, 7 and 28 days). These were then split in half and stored in plastic wallets until they had reached the required age.

2.15.1 1, 8-Diaza-9-fluorenone (DFO)

DFO (traditional method)

DFO powder (0.5 g) was placed in a 2 L glass beaker along with methanol (100 mL), ethyl acetate (100 mL) and acetic acid (20 mL) and stirred with a magnetic stirrer until a clear, yellow solution was produced. Petroleum ether (780 mL) was then added with stirring and the resulting solution was stored in a dark bottle in the solvent cupboard until required.

The samples were placed into a shallow tray containing enough DFO solution to completely cover the samples, then after approximately 5 seconds the samples were removed and placed onto paper to dry. Finally, the samples were placed in the DFO oven (Heraeus instruments UT 6200) at a temperature of 100 ºC for 20 minutes. All the samples were viewed with white light as well as under the Green (500-560 nm) Crime lite and were all photographed with the Nikon D40 camera fitted with an orange 549 nm filter. The samples were also photographed with the Quaser using the 497 nm viewing filter and an excitation filter of 473-548 nm.

DFO (dry method)

Stock solution (50 mL) was used to coat 32 cm filter papers (W and R Balston Ltd. No. 44,) and these were hung in the fume hood until dry and then stored in a plastic bag in the solvent cupboard.

The samples were "sandwiched" between the DFO soaked filter papers and steamed with a Tefal Superglide IS iron (1 minute) containing acetic acid (5 %) solution. The samples were then removed from between the filter papers and placed between weighted (6 x 1 Kg weights) steel A4 sized plates and heated in the DFO cabinet to 110 ºC for 10 minutes.

The samples were then viewed and recorded as described in the traditional DFO method section.

Prior to the trials, the temperature of the DFO cabinet was determined by use of a digital thermocouple (RS 206-3738) to ensure it was at the correct operational temperature of either 100 °C for the traditional method or 110 °C for the dry method.

2.15.2 Ninhydrin

The stock solution was prepared by placing ninhydrin (25 g) in a clean dry 400 mL beaker, adding ethanol (225 mL) whilst stirring with a magnetic stirrer to produce a slurry. Ethyl acetate (10 mL) was then added followed by acetic acid (25 mL) with continuous stirring until a clear, yellow solution was produced. The solution was then stored in a dark glass bottle, at room temperature until required.

To produce the required working solution, the stock solution (52 mL) was placed in a 2 L beaker and petroleum ether (1000 mL) added with stirring, to afford a pale yellow solution. This was then transferred to a dark glass bottle and stored at room temperature.

Traditional method

The samples were processed following the standard operating procedures (SOPs) as described in the Fingerprint manual (Bowman 2005). The samples were placed in a shallow tray of the solution for approximately 5 seconds and then on paper until dry. They were then placed on cardboard in the ninhydrin oven (Gallenkamp BR185H SP) at 80 °C and a relative humidity of 65 % for 5 minutes, as per SOPs. Finally, the samples were viewed under white light and photographed with a Nikon D40 camera.

Prior to the start of the trial, the temperature of the cabinet was determined by the use of a digital thermocouple (RS 206-3738) and the humidity by means of a humidity meter (Fluke 971) to ensure they were at the correct operational needs of 80 °C and a relative humidity of 65 %. The cabinet was also profiled to determine whether there was an even humidity within the cabinet. This was carried out by placing pieces of paper loaded with a single latent fingermark at different positions in the cabinet and comparing the quality of marks developed. Using this technique, it was determined that the cabinet did in fact have an even distribution of humidity and therefore samples could be placed in all areas of the cabinet.

Steam Iron method

The samples were subjected to heat and humidity by moving a steam iron (Tefal Superglide IS) to approximately 3 cm over the sample surface for 30 seconds. The temperature of the metal plate on the steam iron was measured by means of a digital thermocouple, RS 206-3738 (100-120 °C) and humidity by means of a Fluke 971 humidity meter (relative humidity 85 %). The samples were then viewed under white light and photographed with a Nikon D40 camera.

The no heat or humidity method

The samples were dipped in the DFO solution for 5 seconds and then left to dry without any addition of heat or humidity. Once dry they were recorded under white light by photographing with a Nikon D40 camera.

All samples were viewed, photographed and details recorded after each process was complete. The samples were then stored in the plastic wallets and re-examined after one week and one month to determine whether extra ridge detail or colouration (Ruhemann's purple) had developed.

2.15.3 Small particle reagent (SPR)

A concentrated solution was prepared by measuring tap water (500 mL) into a clean 600 mL beaker, to which 10 % AEROSOL OT solution (7.5 mL) was added with stirring. Next, molybdenum disulphide (50 g) was weighed and placed into a clean 1 L beaker and small portions of the detergent solution were added until a smooth paste was achieved. Then, half the remaining detergent solution was added with stirring until a slurry was produced and this was transferred to a clean plastic bottle and the remaining detergent was added to the beaker to transfer any remaining powder to the bottle.

The working solution was prepared by shaking the concentrated solution, pouring it into a plastic 5 L bottle and adding tap water (4.5 L). This solution can be kept indefinitely, however it needed to be shaken before each use to ensure even distribution of reagent.

The fabric swatches were immersed in the solution and held stationary (30 seconds) in the suspension near the bottom of the basin. They were carefully removed, inverted and drawn through a tank of tap water and dried by hanging on a "washing line". The swatches were then viewed under white light and photographed using a Nikon D40 camera.

2.15.4 Fluorescent fingerprint powders

In a darkened room, using the blue (430-470 nm) Crime lite and the yellow goggles (476 nm), a magnetic brush was used to apply the red fluorescent magnetic Crime Scene Investigation Equipment Ltd.) to the fabric swatches to enhance the planted latent marks. The swatches and any visualised marks were illuminated with the blue Crime lite (420 – 470 nm) then photographed using the Nikon D40 camera fitted with a yellow filter (476 nm).

3. VISUALISATION OF FINGERMARKS ON FABRIC SWATCHES BY MEANS OF VACUUM METAL DEPOSITION (VMD)

3.1 Aims

To use VMD in order to visualise fingermark and palm ridge detail on fabrics and to discover the quality of marks visualised on cotton, nylon, polyester and polycotton samples and determine the variability between fifteen donors and the effect of ageing the samples over a 28 days.

3.2 Grading of marks

(0) No development – negative, no visible or recognisable marks on fabric.

(1) "Empty" marks - could see where the donor had touched the fabric but no ridge detail on fingertips or palm.

(2) Fair – Full pattern and ridge flow on 1 or 2 fingers or approximately 1/3 partial detail on all the fingers and/or palmar flexion creases visible, but not enough detail for identification.

(3) Good - ridge characteristics (Galton details) visible on at least 3 fingers or approximately 1/3 to 2/3 partial detail on all fingermarks.

(4) Excellent - good ridge detail on all 5 fingertips and palm with visible pores, ridge edge detail and ridge flow.

3.3 Donor one

Figure 3.1 shows the gradings for donor one on cotton, nylon, polyester and polycotton. Interestingly, this donor had a rating of medium to poor on cotton and was the only donor to deposit any ridge detail on cotton [Figure 3.2]. All the other cotton samples were graded as empty (days 3 – 7, 21 and 28). These empty samples ranged from full grab impressions to just finger impressions, which means that even though an identification could not be made as there was no ridge detail, they could have produced a target area from which DNA may be obtained.

On nylon this donor gave an overall rating of good, due to there being 3 excellent samples (days 2 [Figure 3.3], 5 and 14), 4 good samples (days 1, 3, 6 and 7) and 3 fair samples (days 4, 21 [Figure 3.4] and 28). As these samples contain ridge detail and palmar flexion creases, of varying strengths, it may be possible to identify the individual from this information.

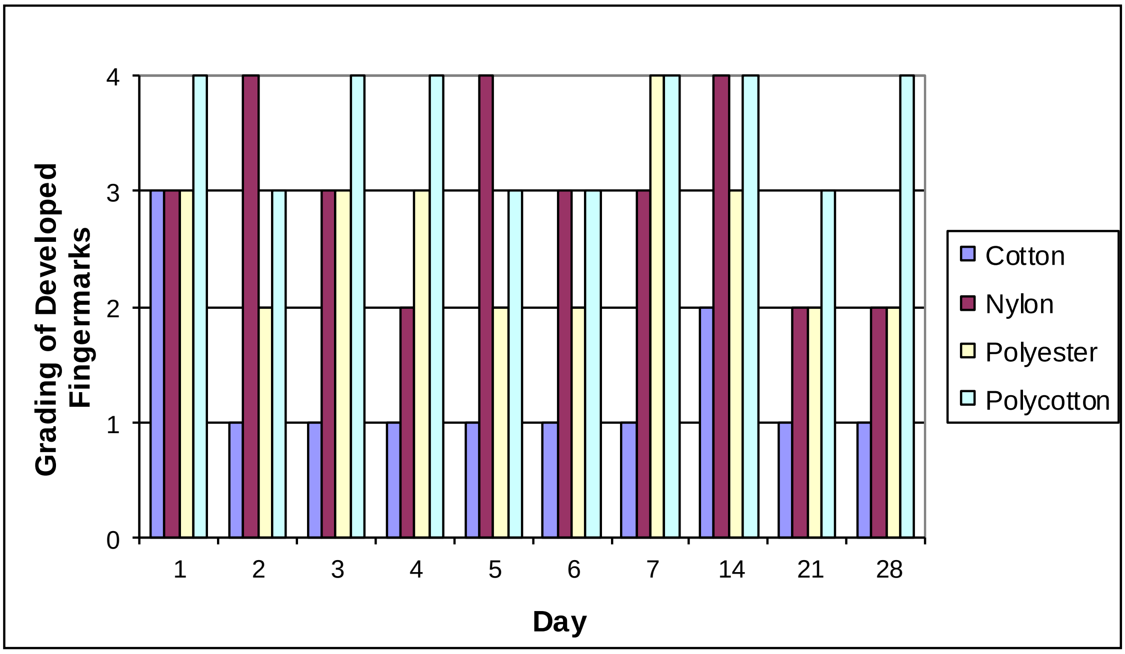


Figure 3.1: Grades of fingermarks (1 – 4) for donor one over the 10 day timeline (days 1 – 7, 14, 21 and 28) on cotton, nylon, polyester and polycotton, visualised with VMD.

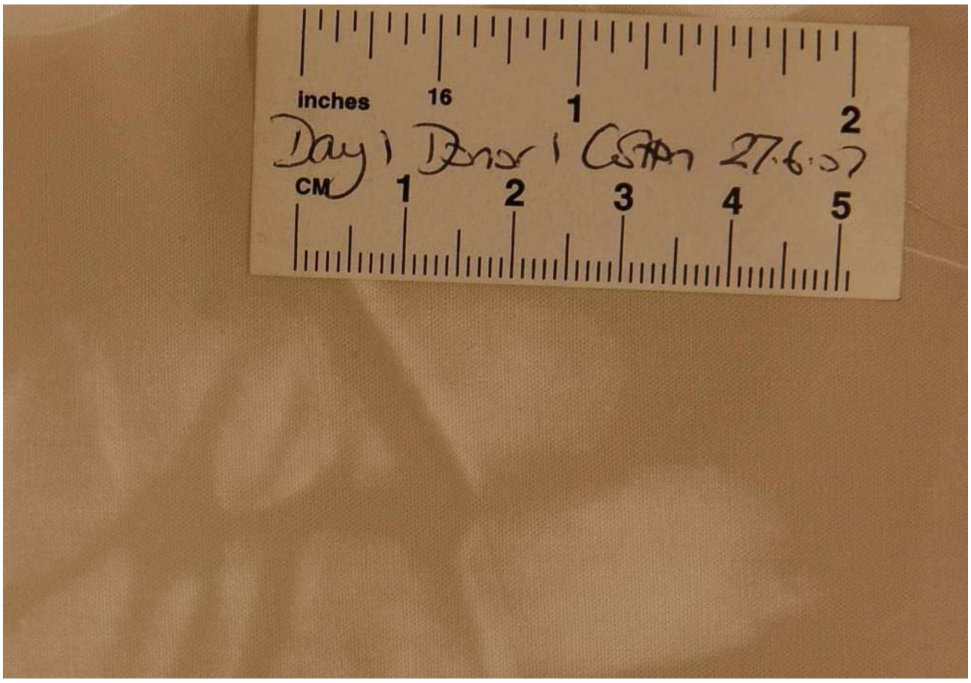


Figure 3.2: Close up of faint ridge detail in the right index finger of donor one, on a day old cotton fabric. Sample image was taken with a Nikon D40 using white light.

The polyester samples produced a good donor rating, with all the samples providing a target area for DNA. There was ridge detail on days 1, 3, 4, 7 and 14, with all other days (2, 5, 6, 21 and 28) having palmar flexion creases but empty marks. All this information could however help lead to identification – there has been much work done with palmar flexion creases and their use in identification over the last 10 years (Wormack 2012). The fact that all of the swatches contain palmar flexion creases indicates that the possibility of identifying this donor from any of the marks left is quite good, even with the samples (days 21 and 28) that only contained some palmar flexion creases.

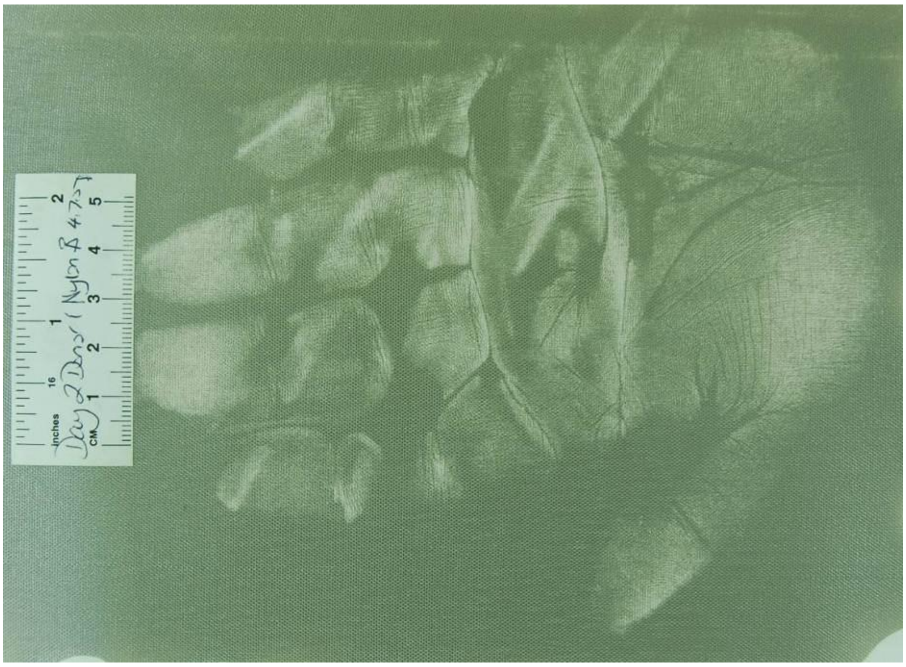


Figure 3.3: Example of an excellent sample (grade 4) from donor one (day 2 on nylon), containing ridge detail on all fingers and thumb as well as palmar flexion creases. Photograph taken with a Nikon D40 using white light.

Considering, the polycotton samples this donor had a rating of good due to all days producing some ridge detail and palm lines even in the later days. For example, the samples ranged from the marks having palmar flexion creases and all fingers with ridge detail (days 1, 3, 4, 7, 14 and 28) to those with missing portions of detail on fingers (days 2, 5, 6 and 21).

Overall, the average grade for each fabric can be calculated by adding all the grades for all the days for each fabric and then dividing by 10 (the number of days in the timeline). Therefore, with this donor, polycotton (average grade of 3.6) was the most successful fabric followed by nylon (3), polyester (2.6), and finally cotton (1.30). The propensity of a fabric to show high rating was determined by the donor and the number of high graded samples obtained. When considering these high graded samples and their level of ridge detail it can be considered that the most successful day for each fabric was: day 7 for polyester (grade 4), days 2, 5 and 14 (grade 4) for nylon, days 1, 3, 4, 7, 14 and 28 (grade 4) for polycotton, and day 1 for cotton (grade 3). Therefore, with this donor there does not seem to a consistent day for the collection of a "good" mark. This is demonstrated when the overall gradings for all fabrics is considered; this donor had no 0 grades, only 20 % were grade 1, this increased to 23 % for grade 2, which would contain some ridge detail, then a high of 32 % for grade 3 and dipping to 25 % for grade 4, both of which would contain identifiable ridge detail.

Figure 3.4: Example of a fair sample (grade 2) from donor one (day 21 on nylon), containing palmar flexion creases and empty marks with no ridge detail. Photograph taken with a Nikon D40 using white light.

The level of ridge detail observed does seem to be dependent on the fabric type and, most likely, some influence from the donor – diet, their activity level and their temperature (Ramotowski 2001; Yamashita and French 2011), as to the level of detail left on the swatch. With this donor all the fabrics produced identifying ridge detail, both in the form of fingermark ridges and palmar flexion creases through the whole of the timeline, with the exception of cotton which only had ridge detail on the freshest sample (day 1). Thus, this donor appears to leave identifying information on three out of the four fabrics as well as obvious target areas that may lead to DNA collection and therefore a DNA profile.

3.4 Donor two

This donor [Figure 3.5] had a rating of poor for cotton due to there being four instances of no development (days 2 – 4 and 6) and five empty samples (days 5 and 7 – 28). These samples ranged from fingertips to fingers and palmar flexion creases, such as the moderate sample (day 1) which gave a grab image and detail in the palm. The donor rating for nylon was medium due to six out of the ten samples being good (days 1 and 5) or fair (days 3, 4, 6 and 28), thus giving ridge detail in the palm as well as fingertips. While the donor rating for polyester was medium as only one sample was rated as having good ridge detail (day 1) and the rest having, at most, palmar flexion creases. The donor rating was medium on the polycotton due to the increase in samples showing ridge detail. The days with palmar flexion creases (1, 6, 7 and 28) and those with ridge detail (1 and 6) give a higher chance of identification via ridge detail compared to polyester, as this fabric only had ridge detail on the freshest sample - day 1.

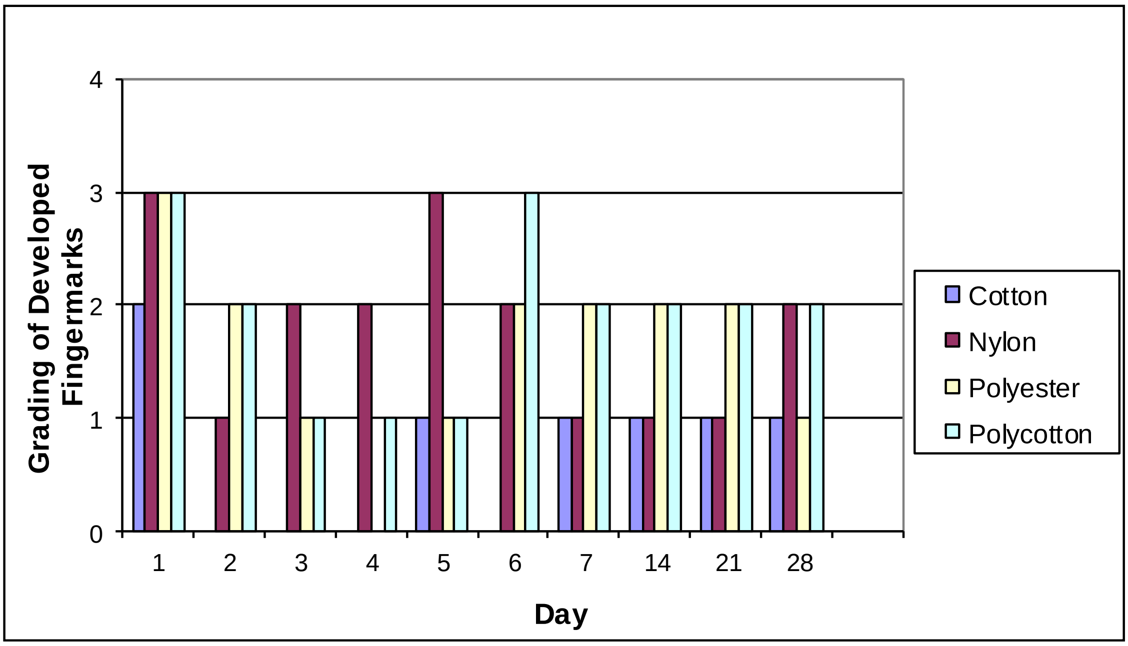


Figure 3.5: Grades of fingermarks (0 – 3) for donor two over the 10 day timeline (days 1 – 7, 14, 21 and 28) on cotton, nylon, polyester and polycotton, visualised with VMD.

The ridge detail from this donor is mostly in the form of palmar flexion creases with the odd fingermark ridge detail on the fresher samples or shinier fabrics.

Therefore, with this donor, identification would be more likely from the DNA collected from the target areas, as demonstrated by the collaborative work carried out in conjunction with Ignacio Quinones Garcia (Quinones, I. 2012. pers. comm., 15 March; Quinones Garcia 2011). This work showed that it was possible to achieve full DNA profiles from samples first treated using the VMD process, as the marks visualised by the VMD process allowed the operator to target an area that had been touched.

Overall, for this donor the fabrics can be rated in order of highest number of successful ridge detail as polycotton, nylon, polyester and cotton and the most successful days were 1 and 6 (grade 3) for polycotton, days 1 and 5 (grade 3) for nylon, day 1 (grade 3) for polyester and day 1 (grade 1) for cotton. The overall average grading reinforces this, with polycotton 1.9, nylon 1.8, polyester 1.6, and cotton only 0.7.

Though this donor generally had good development of their palmar flexion creases they tended to have empty marks with no ridge detail. Overall, only half the swatches contained detail of one form or another – 13 % at 0 and 37 % at 1, with palmar flexion creases in 37 % of the swatches (grade 3) and only 13 % (grade 2) with some form of ridge detail. So, the only way identification could be made with this donor on polyester would be from the palmar flexion creases or from the possibility of DNA extracted from targeting the areas visualised with the VMD process.

3.5 Donor three

Figure 3.6 shows that this donor had a rating of poor for cotton, as all the samples were either empty (days 1, 2, 3, 5, 6 and 7) or showed no development (days 4, 7, 21 and 28). This donor's rating for nylon is also poor, as six out of the ten samples were empty (days 1, 2, 6, 14 and 21) or showed no development (day 28). Days 3, 4, 5 and 7 are fair, giving detail in the palm which may help with identification. The polyester rating for this donor was again poor with only two days (5 and 7) producing any identification marks – that of palmar flexion creases. Finally, with the polycotton fabric the donor rating was again poor with only days 2 and 3 producing any identification marks – some palmar flexion creases on day 2 and faint ridge detail on day 3.

Overall, this donor does not tend to leave identifying marks in the form of ridge detail – there were only two samples that had fingermark ridge detail and four that had palmar flexion creases. None of this donor's samples were graded above 2; 20 % were graded 2, 52 % were grade 1 and 28 % were 0. This donor left few marks or areas to target for DNA collection - in the case of polycotton only half of the samples had areas to be targeted and some of these only possible fingertip marks thus could be artefacts of the process and not areas of contact at all.

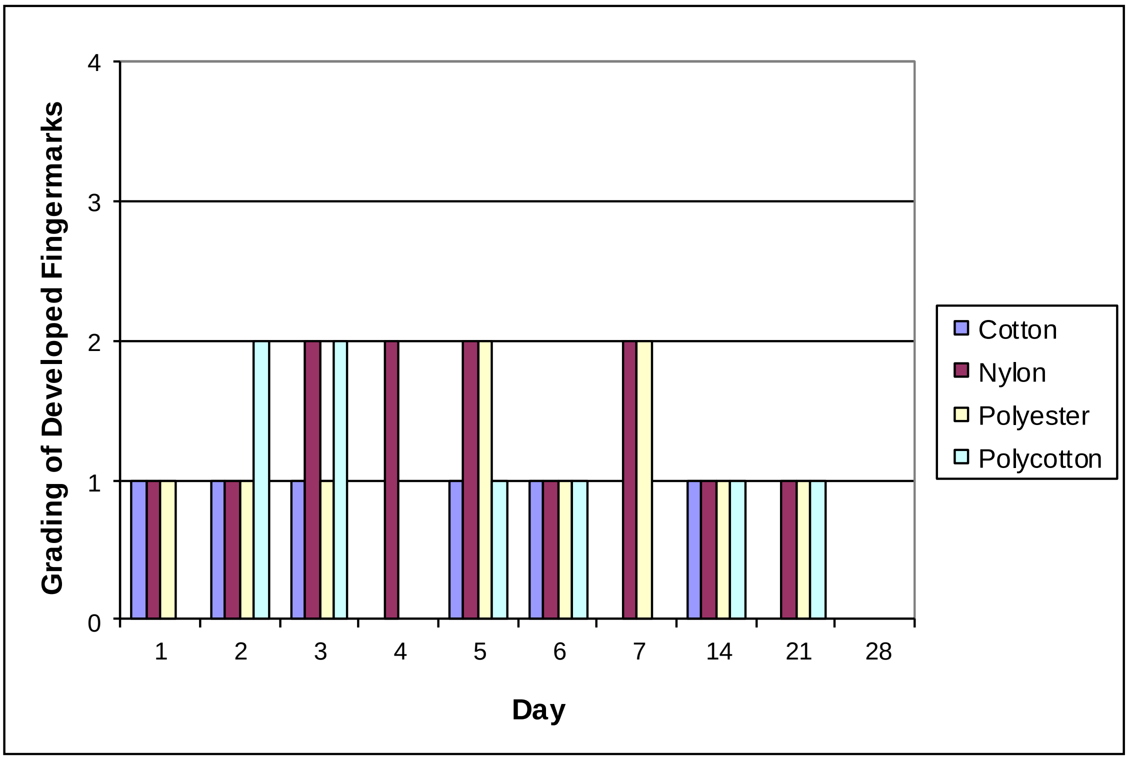


Figure 3.6: Grades of fingermarks (0 – 2) for donor three over the 10 day timeline (days 1 – 7, 14, 21 and 28) on cotton, nylon, polyester and polycotton, visualised with VMD.

Therefore, the fabric ranking for this donor was nylon (1.3), due to its overall grade of 1.3 and that this fabric had the highest number of grade 2 samples (days 3, 4, 5 and 7); followed by polyester (1) with grade 2 samples on day 5, polycotton (0.8) grade 2 samples on days 2 and 3, and cotton (0.6) which was only grade 1 for its positive samples (days 1, 2, 3, 5, 6 and 14). As there is little to no ridge detail with this donor and the only days containing any ridged detail were only grade 2 the likelihood of this donor being identified is quite low.

3.6 Donor five

This donor [Figure 3.7] was poor on cotton, as five of the samples are classed as no development (days 1, 2, 7, 21 and 28) and five are empty (days 3, 4, 5, 6 and 14) with only faint grab or just fingertip marks, leading to an overall grading of 0.5. The nylon samples gave a good to medium donor rating as days 1 to 7 showed fair to excellent results producing detail in the palms and fingertips. Days 14 to 28 though empty, produced grab impressions with some palmar flexion creases, which resulted in an overall grading of 2.3. The polyester samples gave a donor rating of poor due to one sample having no development (day 6), five days only having faint or possible marks (days 1, 4, 5, 14 and 21) and only three days having fair ratings (days 2, 3 and 7), thus giving an overall grading of 1.3. The marks on the polycotton samples led to a medium to good rating, with nine samples containing some level of detail and only two samples with no development (days 6 and 28). Those with detail ranged from giving full grab with palmar flexion creases and ridge detail (days 2, 3, 4, 7, 14 and 21) to those with palmar flexion creases but empty marks (days 1, 5, and 7), resulting in an overall grading of 1.8 for polycotton. When combining all the samples, the overall grades were: 20 % at grade 0 with no ridge detail, 35 % grade 1, 25 % grade 2, 17 % grade 3 and only 3 % grade 4.

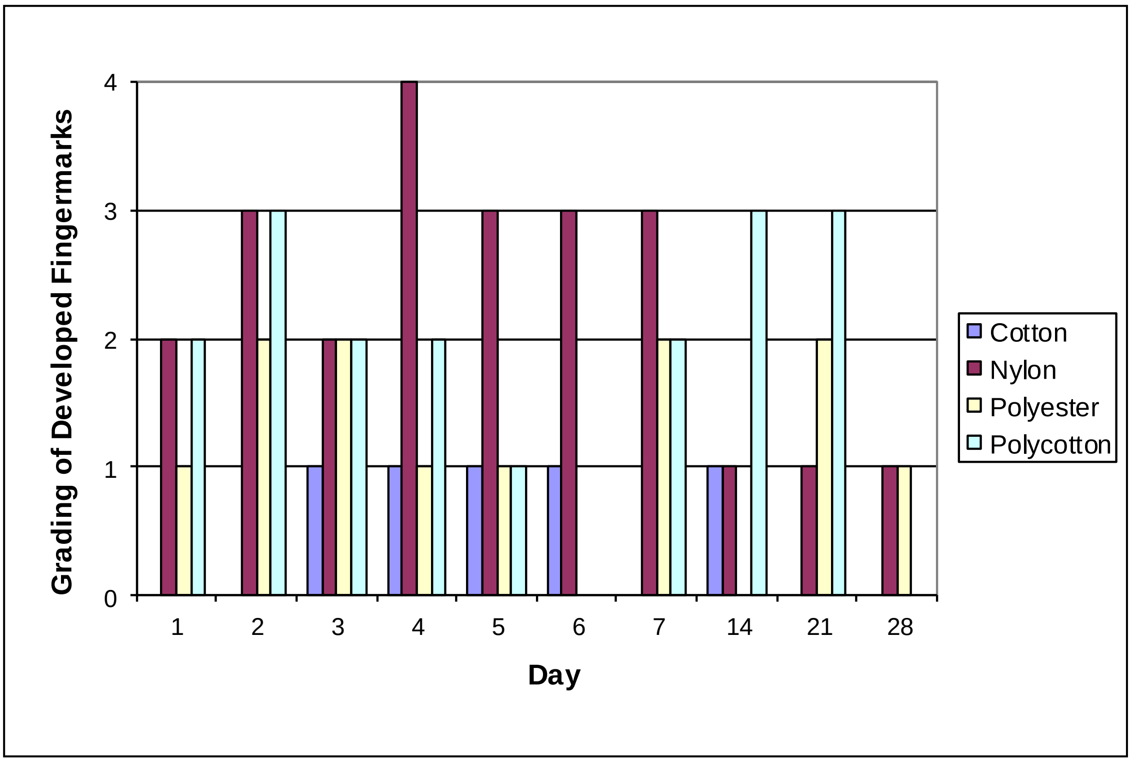


Figure 3.7: Grades of fingermarks (0 – 4) for donor five over the 10 day timeline (days 1 – 7, 14, 21 and 28) on cotton, nylon, polyester and polycotton, visualised with VMD.

Therefore, this donor left some form of good ridge detail on nylon and polycotton, with less on polyester and none on the cotton. They did however leave target areas on the majority of fabric days, except cotton days 1, 7, 21 and 28, polyester day 6 and polycotton days 6 and 28. Again, even though these empty samples were small they could yield DNA, thus this combination of the ridge detail and possible DNA could aid in the identification of this donor.

For this donor, the fabrics were rated, in order of observing ridge detail as nylon, polycotton, polyester and cotton. The most successful days were 2, 14 and 21 for polycotton (grade 3), day 4 for nylon (grade 4), days 2, 3 and 7 for polyester (grade 2) and again this donor had no grade 2 or above swatches for cotton.

3.7 Donor six

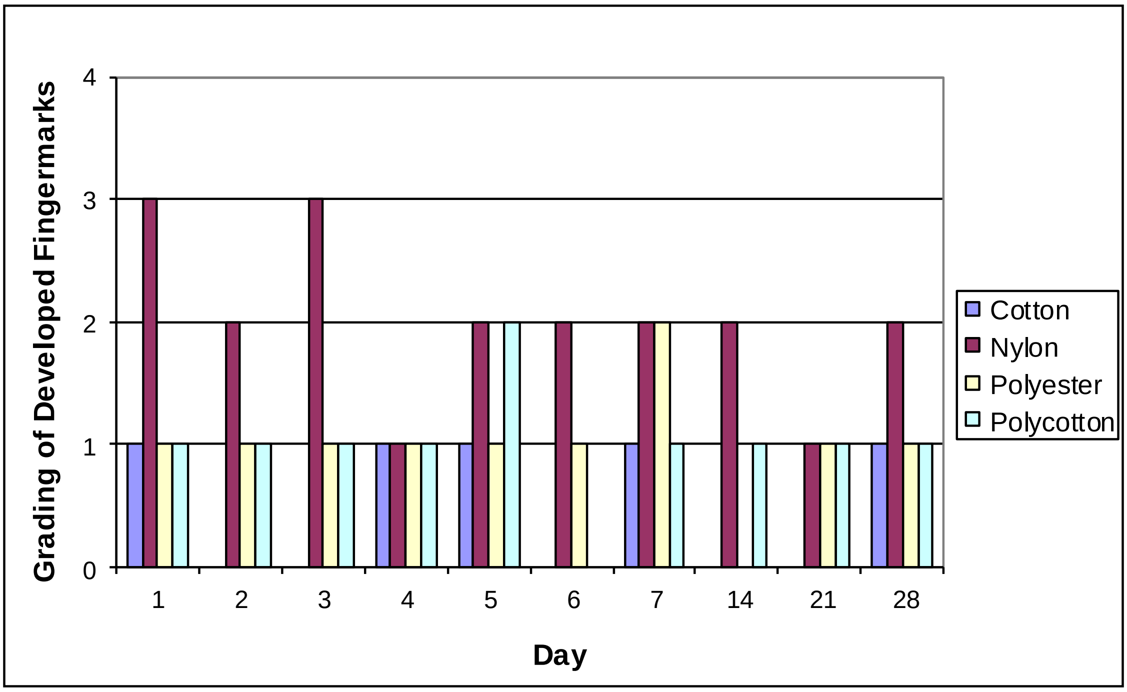


Figure 3.8: Grades of fingermarks (0 – 3) for donor six over the 10 day timeline (days 1 – 7, 14, 21 and 28) on cotton, nylon, polyester and polycotton, visualised with VMD. This set is missing a sample for nylon day 28.

Donor six was poor on cotton as there was either no development (days 2, 3, 6, 14 and 21) or only small target areas, such as faint fingertip marks or partial grabs (days 1, 4, 5, 7 and 28) [Figure 3.8]. Of all these samples it was only on day 1 that a full grab was visualised, but even here the marks were empty, so no ridge detail was present and resulted in an overall grading of only 0.5. The nylon rating for donor six was good to medium, with two of the samples being graded as good (days 1 and 3) with detail such as palmar flexion creases and ridge detail on two fingers; six fair samples (days 2, 5, 6, 7, 14 and 28) ranging from some palmar flexion creases to faint areas of ridge detail. The remaining two samples had possible fingertip marks, thus were graded as empty (days 4 and 21); overall this donor achieved a grading on nylon of 2. With polyester this donor had a poor rating as all the samples, with the exception of day 7 (fair) and day 14 (no development), were classed as empty. The fair sample on day 7 only contained some palmar flexion creases and no other ridge detail, thus overall this fabric had a grade of 1. Polycotton also had a poor rating for donor six, again due to the majority of samples only having empty ratings (days 1, 2, 3, 4, 7, 14, 21 and 28). Day 5 was fair with only signs of a faint grab, though there were a few palmar flexion creases and some very faint ridge detail on the thumb. Day 6 was graded as no development, though there was a possible thumb and finger mark. Therefore, polycotton showed an overall grade of 1.

With the grades all combined donor six had 60 % of swatches graded 0 (20 %) and 1 (40 %), thus reinforcing that this donor does not consistently leave identifiable marks. The rest of the swatches did contain some form of ridge detail, 27 % were grade 2 and 13 % were graded 3, with the majority of these being found on nylon, a smoother and tighter weave fabric.

Overall, for this donor, the fabrics can be rated in the order: nylon, polycotton, polyester and cotton, with the most successful days being day 1 and 3 for nylon (grade 3), day 5 for polycotton (grade 2), day 7 for polyester (grade 2) and for cotton (either 1 or 0).

3.8 Donor seven

The rating for donor seven [Figure 3.9] on cotton was poor as seven samples (days 1 – 4, 6 and 7) were grade 1, thus only target areas. The nylon samples also gave a poor rating as only two samples (days 1 and 3) were fair, giving some palmar flexion creases, the rest were either empty (days 2, 4, 5, 6, 7 and 21) or no development as in days 14 and 28. Overall, polyester gave a poor rating as five days (1, 2, 4, 14 and 28) gave no development and only possible fingertip impressions (days 1, 2, 4 and 28). Days 3, 5, 6 and 21 gave empty ratings and no ridge detail with day 7 being the only sample to give palmar flexion creases that may help with identification. The day 14 swatch displayed zinc deposits only, therefore did not produce any ridge detail of a target area or area to swab for DNA. Finally, polycotton again produced a poor donor rating with two days (4 and 21) producing no development. The remaining marks (days 1, 2, 3, 5, 6, 7, 14 and 28) left target areas of fingertip impressions to grab impressions, but no ridge detail.

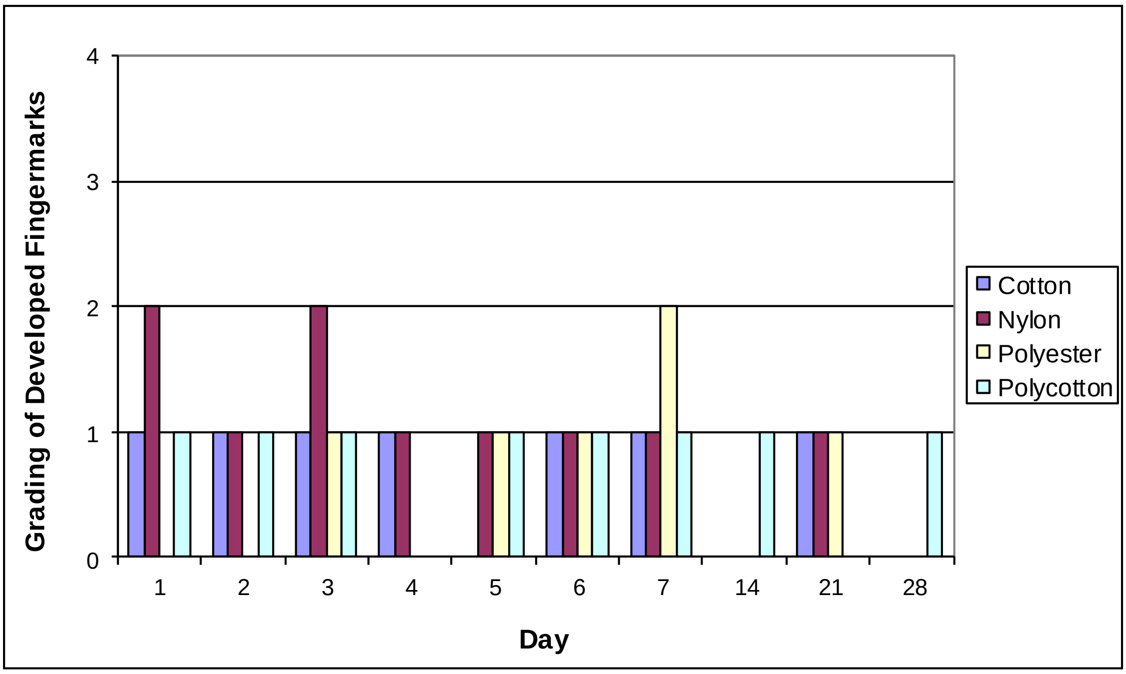


Figure 3.9: Grades of fingermarks (0 – 2) for donor seven over the 10 day timeline (days 1 – 7, 14, 21 and 28) on cotton, nylon, polyester and polycotton, visualised with VMD.

This donor may produce identification from DNA though not every day left a target area for DNA acquisition. This donor did not however leave enough ridge detail to help with identification, therefore the order of fabric ratings are: nylon, polyester, polycotton and cotton. With the most successful days being days 1 and 3 for nylon (grade 2) and day 7 for polyester (grade 2), while neither polycotton nor cotton had any grade 2 or higher samples. The overall grading also illustrated that this donor is unlikely to be identified by ridge detail – cotton had an overall grading of 0.7, nylon 1, polyester 0.6 and polycotton 0.8. This is reinforced by 28 % being grade 0, 62 % were grade 1 and only 10 % were grade 2.

3.9 Donor eight

With this donor [Figure 3.10] the rating was poor for all the fabrics, except nylon which was medium to poor. On cotton half the samples showed no development (days 3 – 7) and only zinc deposition though- day 7 did have a faint mark, which may have been a finger impression. All the other samples were empty with days 1, 2 and 14 being grab impressions, which were either faint or only partial grabs and days 21 and 28 showing only fingertip marks giving a low overall grading of 0.5. The nylon samples all had grab marks, however only four days (2, 5, 6 and 28) had palmar flexion creases thus resulting in an overall grade of 1.5, meaning only a small chance of identification through ridge detail. The polyester samples all produced target areas, but no ridge detail and only palmar flexion creases on day 4 and 5 and an overall grading of 1.1. With this donor the polycotton fabric swatches all contained target areas ranging from fingertip to full grabs, but none contained any ridge detail and only palmar flexion creases on day 5 and so this resulted in an overall grading of 1.

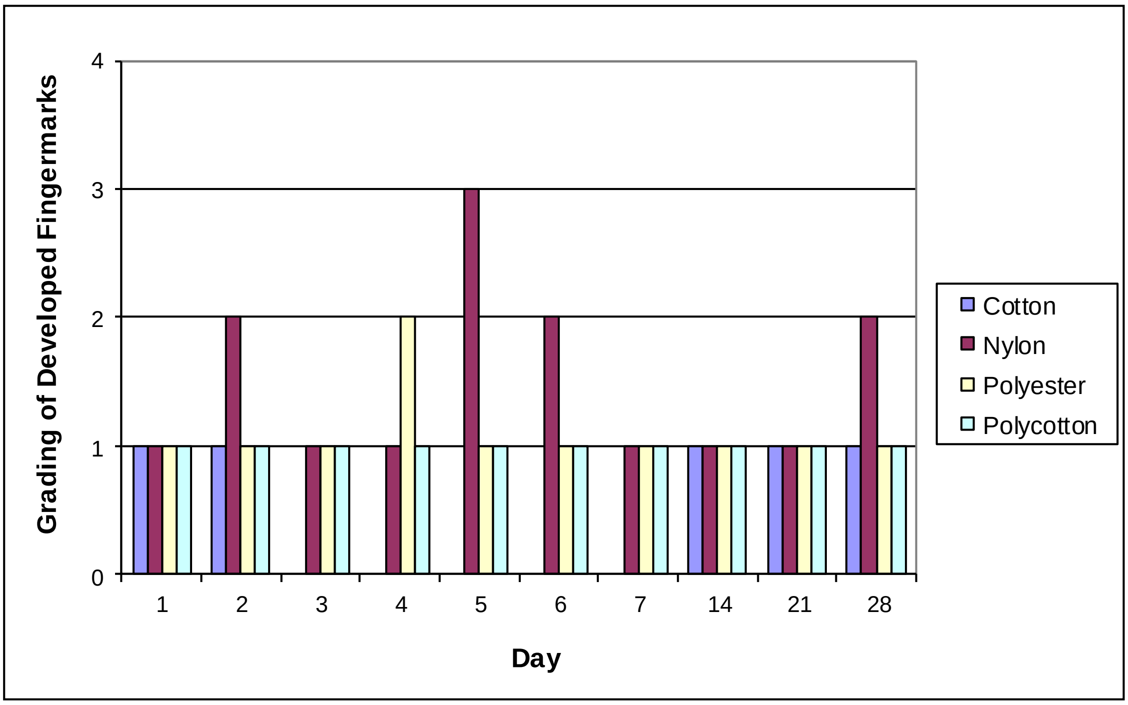


Figure 3.10: Grades of fingermarks (0 – 3) for donor eight over the 10 day timeline (days 1 – 7, 14, 21 and 28) on cotton, nylon, polyester and polycotton, visualised with VMD.

When combining all the fabric grades, donor eight had 12 % of the swatches graded at 0, 75 % at 1 and 13 % at 2. Therefore to produce an identification, it would be from the DNA route as the majority of fabrics allowed a target area to be produced. Thus the fabrics can be rated as: nylon, polyester, polycotton and cotton. With the most successful days being day 3 for nylon (grade 3), day 2 for polyester (grade 2) and, again, no swatches with ridge detail for polycotton or cotton.

3.10 Donor nine

Donor nine [Figure 3.11] had a poor grading for cotton, nylon, polyester and polycotton, due to the lack ridge detail in the majority of samples. Cotton showed an overall grade of 0.5 as it only produced five samples with areas to target for DNA and none of these (days 1, 2, 3, 5 and 21) displayed any ridge detail and the other five samples (days 4, 6, 7, 14 and 28) were graded as zero (no development). Nylon showed an overall grade of 1.1 as there were two fair samples with some palmar flexion creases (days 2 and 7), seven empty samples (days 1, 3, 4, 6, 14, 21 and 28) with only small target areas for possible DNA collection and finally day 5 had no development. Therefore with this lack of detail donor nine had a poor grading. Polyester had an overall grading of 1 as it only produced one fair sample with faint ridge detail on the thumb and first finger (day 3). All other days were empty (rating 1), ranging from faint grab impressions to fingertip impressions only, with the exception of day 4 which had a possible fingertip and thumb impression and therefore had a zero rating. Polycotton produced a fair rating for day 1 as there was ridge detail on the thumb; however the other days were empty so producing an overall grading of 1.1.

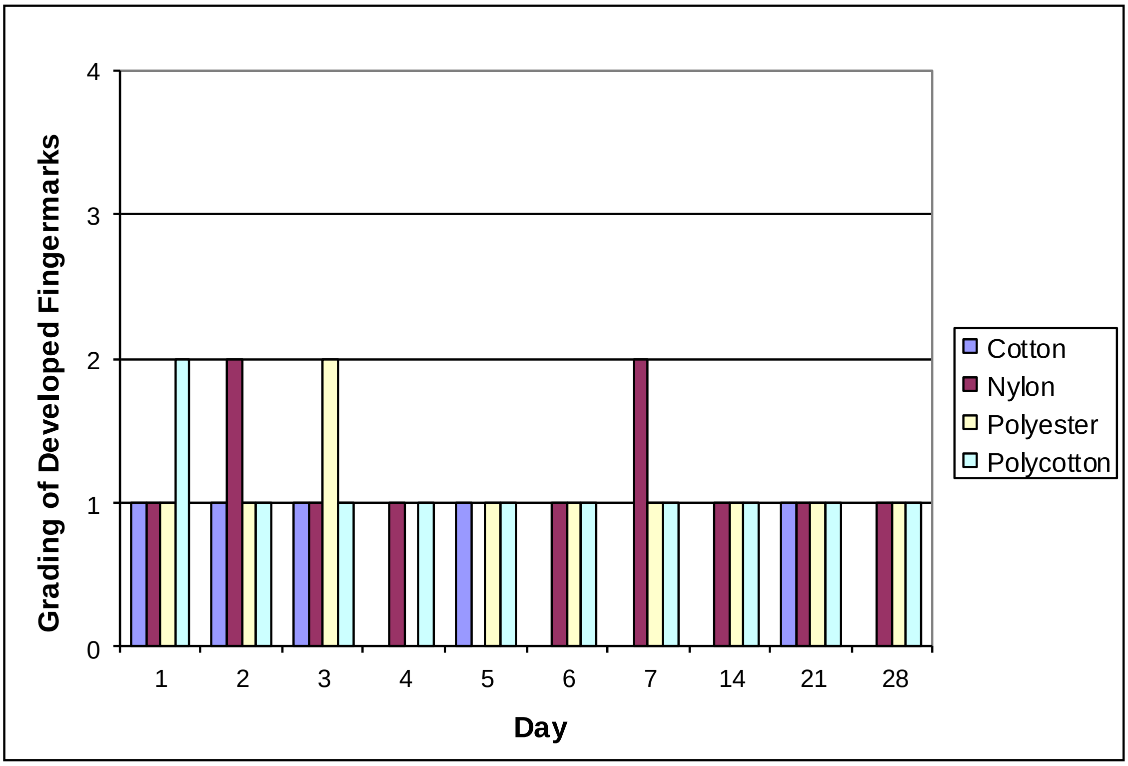


Figure 3.11: Grades of fingermarks (0 – 2) for donor nine over the 10 day timeline (days 1 – 7, 14, 21 and 28) on cotton, nylon, polyester and polycotton, visualised with VMD.

Overall, this donor had a poor rating due to a lack of identifying ridge detail and only had 10 % of swatches graded as 2, 72 % grade 1 and 18 % grade 0, so any identification would have to come from the possible collection of DNA. The fabrics can be still be rated in order of successful ridge detail as nylon, polycotton, polyester and cotton. With the most successful days, all at grade 2, being day 1 for polycotton, days 2 and 7 for nylon, day 3 for polyester, and no grade 2 or above for cotton.

3.11 Donor ten

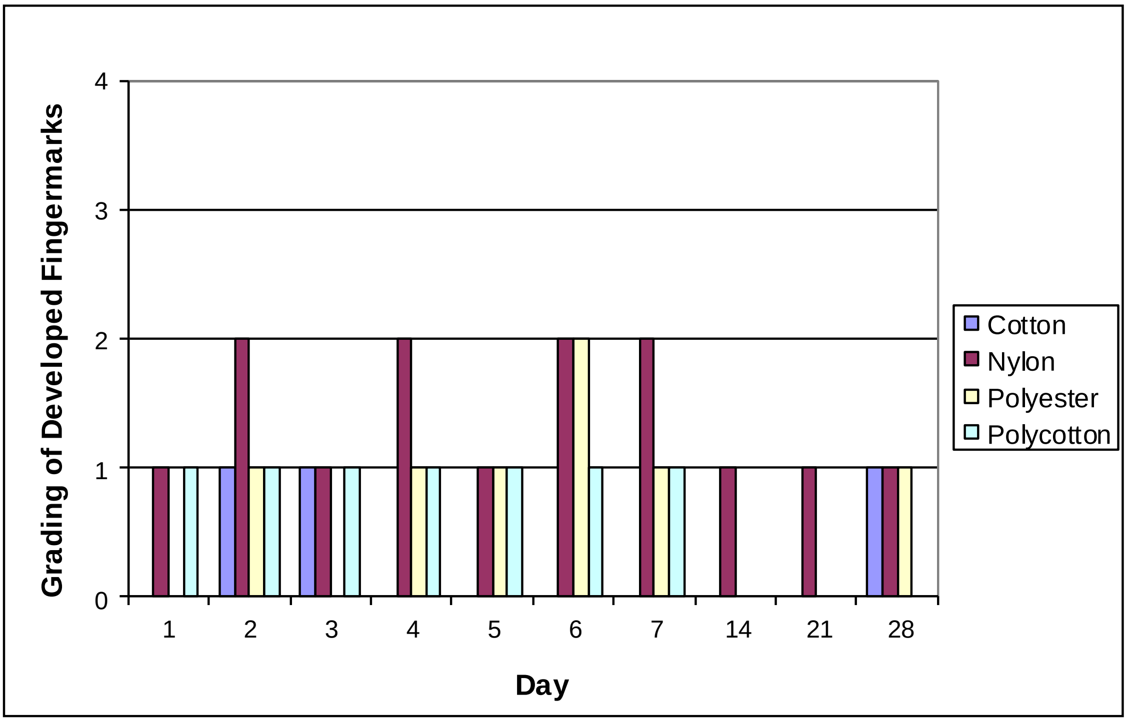


Figure 3.12: Grades of fingermarks (0 – 2) for donor ten over the 10 day timeline (days 1 – 7, 14, 21 and 28) on cotton, nylon, polyester and polycotton, visualised with VMD.

It can be seen [Figure 3.12] that the cotton samples with this donor gave a poor rating as seven of the samples (days 1, 4, 5, 6, 7, 14 and 21) gave no development. The other three samples (days 2, 3, and 28) gave only faint fingertip impressions, thus a small area to target for DNA. With the nylon samples there was a medium to poor rating as there were only four fair samples (days 2, 4, 6 and 7) giving ridge detail in the fingertips and palms. The other six samples were empty, thus only giving a target area for DNA collection. Polyester produced a poor rating with only one fair mark for day 6 containing some palmar flexion creases, five empty ratings with no ridge detail (days 2, 4, 5, 7 and 28) and four no development ratings. Polycotton again had a poor rating with this donor as days 1 to 7 gave empty samples with no ridge detail and days 14 to 28 had no development with only possible fingertip impressions or palmar flexion creases. All the samples could however allow the collection of DNA, as there were possible target areas for collection.

There is the possibility that this donor might be identified from marks on nylon however, it would be the possibility of DNA collection on polyester and polycotton that would be most successful.

The overall fabric rating for this donor is nylon: (1.4), polyester (0.7), polycotton (0.7), and then cotton (0.3). The most successful days (grade 2) were 2, 4, 6 and 7 for nylon, day 6 for polyester, but both polycotton and cotton had no grade above 1. For this donor there is a lack of identifiable ridge detail, the highest graded swatches being grade 2 (13 %), followed by grade 1 (52 %) and grade 0 (35 %).

3.12 Donor eleven

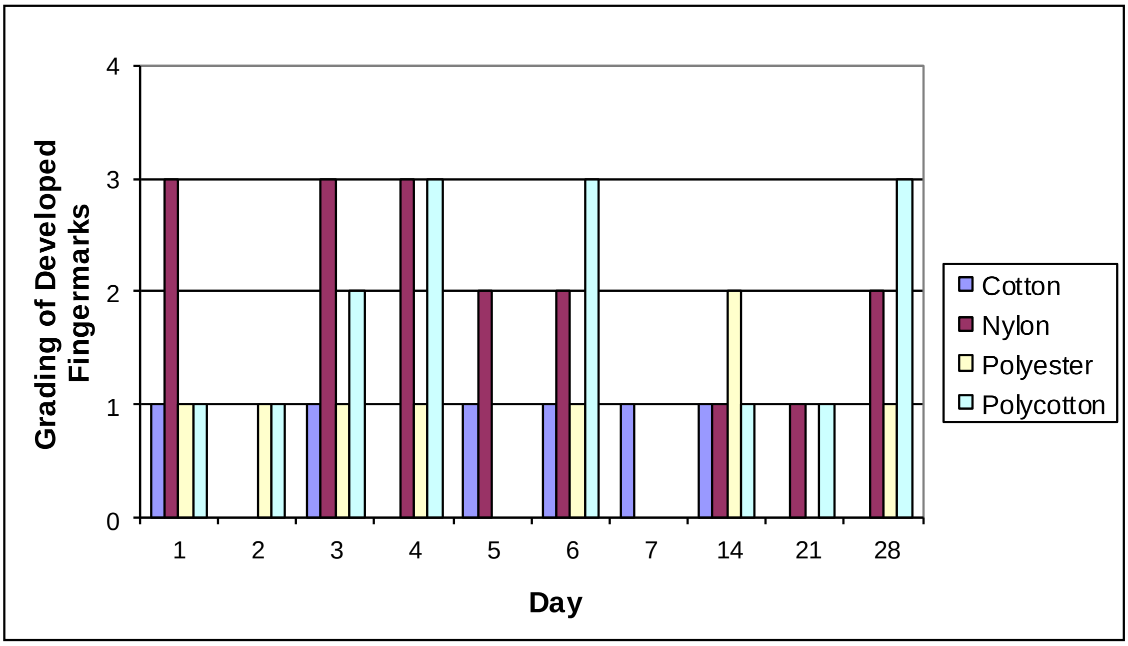


Figure 3.13: Grades of fingermarks (0 – 3) for donor eleven over the 10 day timeline (days 1 – 7, 14, 21 and 28) on cotton, nylon, polyester and polycotton, visualised with VMD.

Donor eleven [Figure 3.13] showed a poor rating for cotton as six samples were empty (days 1, 3, 5, 6, 7 and 14). The other four samples collected were classified as no development (days 2, 4, 21 and 28), however there were marks on these samples that may have been fingertip impressions. The nylon samples led to a donor rating of medium due to a mixture of good (days 1, 3 and 4), fair (days 5, 6 and 28) and empty samples (days 14 and 21) and no development (days 2 and 7). The polyester led to a donor rating of poor as there was only one fair day (day 14) with palmar flexion creases, but no ridge detail, six empty days (1 – 4, 6 and 28) and three no development (days 5, 7 and 21). Day 5 appeared to show only zinc deposits Polycotton showed medium to poor ratings as there was a mixture of good (days 4, 6 and 28), fair (day 3), empty (days 1, 2, 14 and 21) and no development (days 5 and 7).

Overall, though this donor did have some identifiable ridge detail with nylon and polycotton, the overall gradings had 82 % classed as unidentifiable (30 % at grade 0 and 52 % grade 1) and only 18 % being identifiable (10 % at grade 2 and 8 % at grade 3). Therefore, this donor may be more likely to be identified by DNA collection, as all days and fabrics gave some target areas or the possibility of a target area (except polyester day 5). Thus, the overall fabric rating was nylon (1.7), polycotton (1.5), polyester (0.8) and cotton (0.6) and the most successful days were 4, 6 and 28 for polycotton (grade 3), days 1, 3 and 4 for nylon (grade 3), day 14 for polyester (grade 2) and no days for cotton.

3.13 Donor twelve

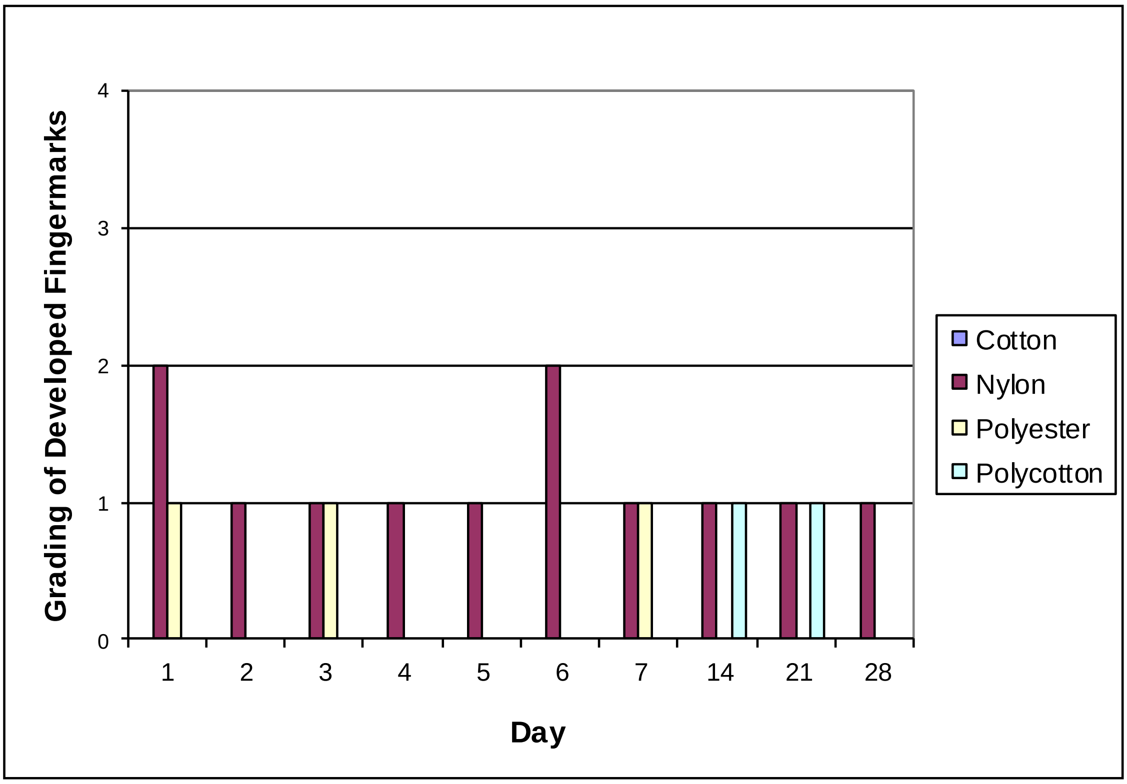


Figure 3.14: Grades of fingermarks (0 – 2) for donor twelve over the 10 day timeline (days 1 – 7, 14, 21 and 28) on cotton, nylon, polyester and polycotton, visualised with VMD.

With donor twelve [Figure 3.14] there was no development on any of the cotton samples with only day 1 giving a possible finger impression, therefore the rating was poor. The rating for nylon was also poor as there were only two fair samples (days 1 and 6), with faint ridge detail on some fingers, while the rest were empty. Polyester also had a poor rating with only 3 days (1, 3 and 7) that were not classed as zero and days 4 and 21 only had zinc deposits. With polycotton, the majority of days had no development and only possible fingertip impressions or zinc deposits. Days 14 and 21, though positive, were empty with only faint fingertip impressions.

Overall this donor produced very little ridge detail or target areas (with the exception of nylon) and therefore little chance of identification. The fabrics can still be rated: nylon (1.2), polyester (0.3), polycotton (0.2) and cotton (0). The only successful fabric with swatches graded higher than 1 was days 2 and 6 for nylon (grade 2) and this donor was poor for all the fabrics and this can be seen with the overall grading percentages of – grade 0 (62 %), grade 1 (33 %) and grade 2 (5 %).

3.14 Donor thirteen

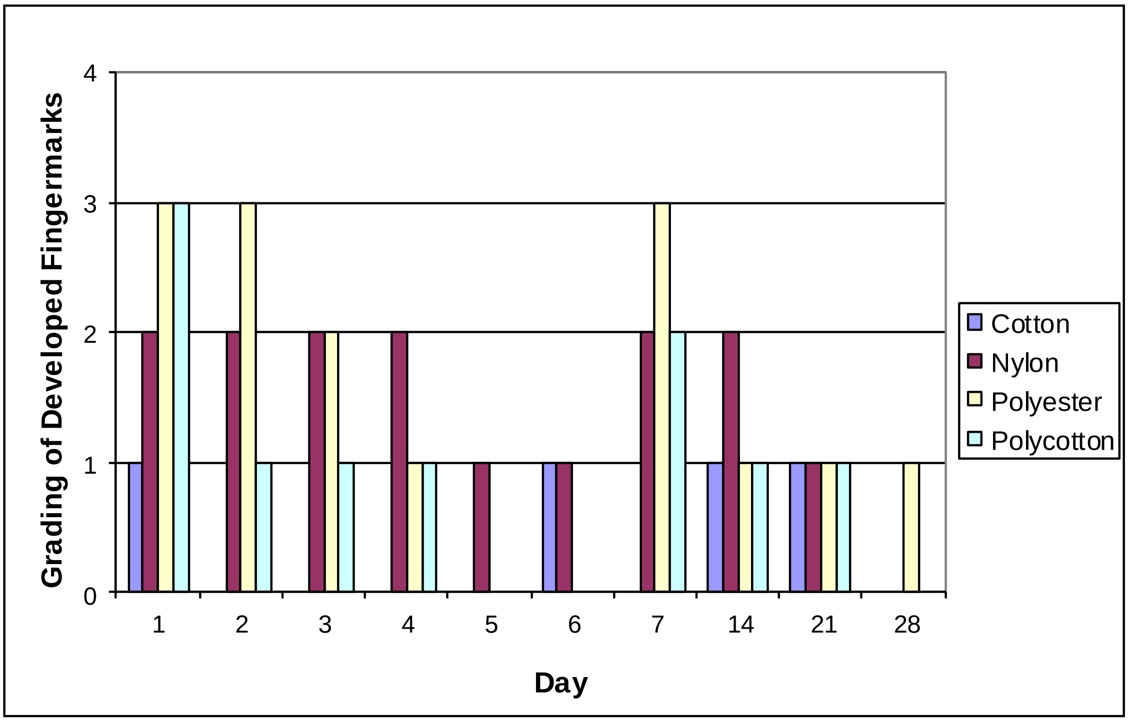


Figure 3.15: Grades of fingermarks (0 – 3) for donor thirteen over the 10 day timeline (days 1 – 7, 14, 21 and 28) on cotton, nylon, polyester and polycotton, visualised with VMD.

The rating for cotton [Figure 3.15] was again poor and of the 10 samples, six contained no development (days 2, 3, 4, 5, 7 and 28). The other samples (days 1, 6, 14 and 21) were empty and only contained small target areas and no full grabs. The nylon rating was medium to poor as there were six fair samples (1, 2, 3, 4, 7 and 14) all containing ridge detail on some fingertips or palms. There were also three empty samples (days 5, 6 and 21), containing faint grab or finger impressions and on day 28 a sample with no development. Therefore, all the samples with the exception of day 28 have areas that could be used to target for DNA. Polyester also had a rating of medium to poor with three good samples (days 1, 2 and 7) which contained palmar flexion creases and some ridge detail on the thumb and first finger. Also, polyester had one fair sample (day 3) with ridge detail on the thumb; four empty samples (days 4, 14, 21 and 28) with faint grab and/or impressions and two samples with no development (days 5 and 6). Polycotton gave a poor rating with only day 1 giving a good rating as there were palmar flexion creases and ridge detail on the thumb and day 7 being fair as there were some palmar flexion creases. Days 2 – 4, 14 and 21 were all empty and days 5, 6 and 28 had no development and only zinc deposits. Therefore days 1 and 7 may help with identification however all days with the exception of 5, 6 and 28 may produce a DNA profile to aid identification.

Overall, donor thirteen is more likely to be identified from DNA rather than from ridge detail. It is still possible to give the fabrics a rating: polyester had some higher grades but the same overall grading as nylon (1.5), polycotton (1) and cotton (0.4). The most successful days for the fabrics were days 1 - 4, 7 and 14 for nylon (grade 2), days 1, 2 and 7 for polyester (grade 3) and day 1 for polycotton (grade 3), while cotton had no grade 2 or above swatches. With the gradings combined the percentages show why this donor was poor. Though there are 10 % of the swatches graded at 3, there were only 20 % grade 2, (thus a combined 30 % with ridge detail) and grade 1 (10 %) and grade 0 (30 %).

3.15 Donor fifteen

This donor [Figure 3.16] had a rating of poor for cotton due to six samples having no development (days 5 – 28) and two empty samples (days 2 and 4) with only finger marks, which resulted in an overall grading of 0.4. The nylon rating for this donor was medium. Day 1 gave no development; days 2, 3 and 7 were classed as good as they all contained palmar flexion creases and detail in some of the fingertips; days 4, 6, 14 and 21 were fair as all contained palmar flexion creases, while day 28 was classed as empty as there was only a grab with no ridge detail. Thus nylon achieved an overall grading of 1.9. The polyester rating was poor (overall grade of 0.6) due to six samples having no development (days 1, 4, 6, 7, 21 and 28) and, of these, only day 4 having possible fingertip and thumb tip marks. Of the four other samples, there were two fair (days 3 and 5) and two empty (days 2 and 14) with only ridge detail on the thumb of day 3 and thumb and three fingers of the day 5 sample. Finally, polycotton was also poor (overall grade of 1) due to only days 1 to 3 producing ridge detail or palmar flexion creases. Days 4, 5 and 14 were empty and days 6, 7, 21 and 28 had no development with only possible fingertip marks on day 7.

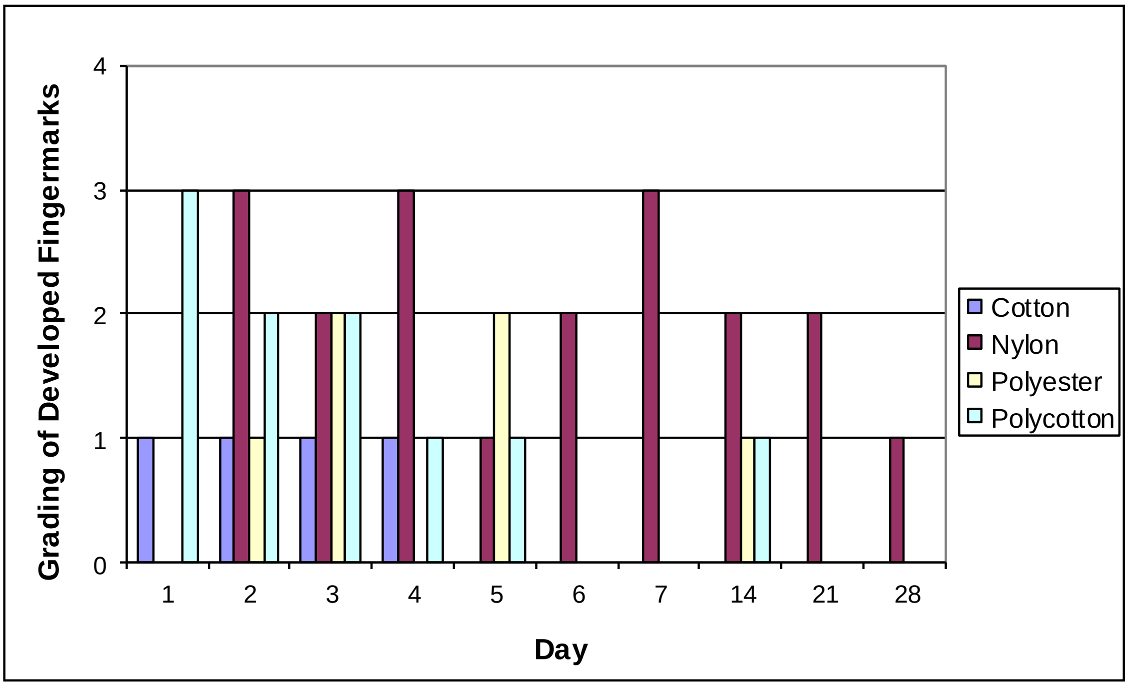


Figure 3.16: Grades of fingermarks (0 – 3) for donor fifteen over the 10 day timeline (days 1 – 7, 14, 21 and 28) on cotton, nylon, polyester and polycotton, visualised with VMD.

When combining all the grades it was determined that this donor produced ridge detail on nylon, polyester and polycotton, though in most cases at low levels – only 10 % grade 3 and 20 % grade 2 with the rest containing no ridge detail, 28 % grade 1 and 42 % grade 0. This donor did however, produce more DNA target areas therefore more likelihood of producing identification from a DNA profile than from ridge detail. Fabric ratings for this donor are nylon, polycotton, polyester and cotton with the most successful days being 2, 4 and 7 for nylon (grade 3), day 3 for polyester (grade 3) and day 1 for polycotton (grade 2) and again no grade 2 or above for cotton.

3.16 Donor sixteen

This donor [Figure 3.17] rating on cotton was poor, with an overall grade of 0.5, due to half the samples being empty (days 1, 3, 7, 21 and 28) and the other half having no development (days 2, 4, 5, 6 and 14). The nylon samples led to a medium donor rating with an overall grading of 1.7 due to two good samples (days 1 and 2); three fair samples (days 3, 6 and 7) and five empty samples (days 4, 5, 14, 21 and

28). The good and fair samples gave varying levels of ridge and palm detail, whereas the empty samples would only be target areas from which to collect DNA.

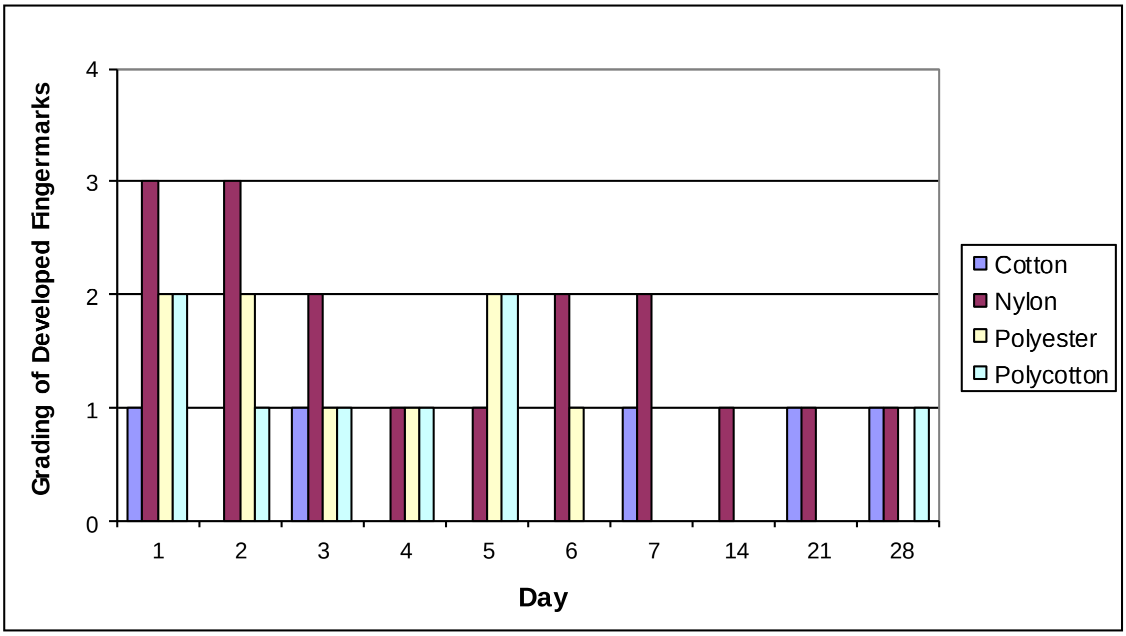


Figure 3.17: Grades of fingermarks (0 – 3) for donor sixteen over the 10 day timeline (days 1 – 7, 14, 21 and 28) on cotton, nylon, polyester and polycotton, visualised with VMD.

The polyester gave a poor donor rating and an overall grading of 0.9 as there were three fair days (1, 2 and 5), three empty samples (days 3, 4 and 6) and four samples with no development (days 7, 14, 21 and 28). Polycotton produced a poor rating (overall 0.8) due to two samples (days 1 and 5) containing some palmar flexion creases and days 2, 3, 4 and 28 producing grab marks. The remaining days (6, 7, 14 and 21) had no development and half were zinc deposits only. Therefore the palmar flexion creases may help in identification, though eight out of the ten samples may yield DNA to produce a profile that could aid in identification.

Overall, this donor may be identified from marks on nylon however for the other fabrics it is the possible DNA that may lead to an identification (except polyester day 28). There were only 25 % of the swatches containing ridge detail – 20 % grade 2 and 5 % grade 3, the rest were 0 (33 %) and 1 (42 %). The overall fabric rating order for this donor is: nylon, polyester, polycotton and cotton and the most successful days were days 1 and 2 for nylon (grade 3), days 1, 2 and 5 for polyester (grade 2) and days 1 and 5 for polycotton (grade 2) and again no swatches graded higher than 1 for cotton.

3.17 Donor twenty

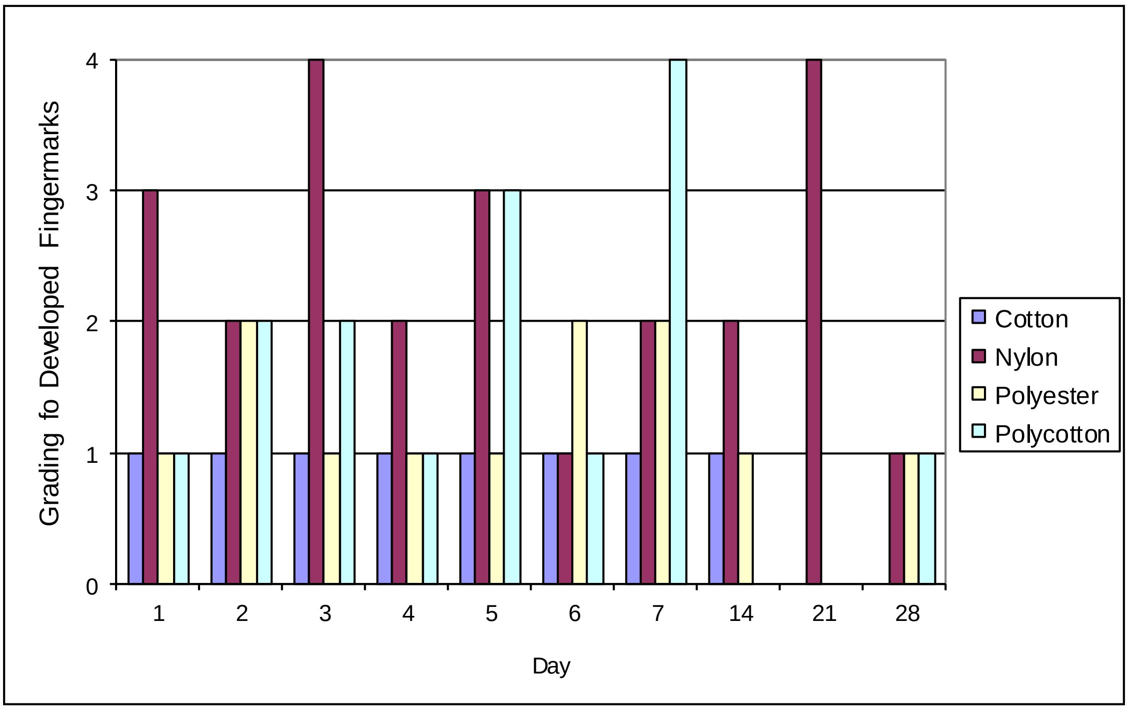


Figure 3.18: Grades of fingermarks (0 – 3) for donor twenty over the 10 day timeline (days 1 – 7, 14, 21 and 28) on cotton, nylon, polyester and polycotton, visualised with VMD.

This donor [Figure 3.18] had an overall grading of 0.8 (poor) for cotton as eight of the ten samples (days 1 – 14) were empty, while the other two samples showed no development. The nylon rating was good (overall grading 2.4) with a mix of fair to excellent samples and only one empty sample (day 28). The fair samples on days 2, 4 and 7 all contained some ridge detail and on day 14 there were palmar flexion creases. The good samples on days 1 and 5 both contained palmar flexion creases and ridge detail on three to four digits, while the two excellent samples (days 3 and 21) showed palmar flexion creases and ridge detail on all digits, with day 21 having some of the palm missing. The polyester rating was poor with three samples being fair (days 2, 6 and 7) with only palmar flexion creases and empty marks. The remainder (days 1, 3, 4, 5, 14 and 28) were empty with only target areas and no ridge detail, while day 21 had no development, only a possible thumb mark for DNA collection and an overall grading of 1.2. The polycotton samples (overall grading of 1.5) produced a medium to poor rating as there was an excellent sample (day 7) and a good sample (day 5) that both produced ridge detail. The rest were fair (days 2 and 3) or empty (days 14 and 21).

Overall, nylon and polycotton produced ridge detail that could aid with identification and accounted for the majority of the swatches graded 2 and above including 8 % having grade 3 and 4. The fabric rating order for this donor was: nylon, polycotton, polyester and cotton and the most successful days were 3 and 21 for nylon (grade 4), days 2, 6 and 7 for polyester (grade 3) and day 7 for polycotton (grade 4) and no grade 2 or above swatches for cotton.

3.18 Overview of donor grading

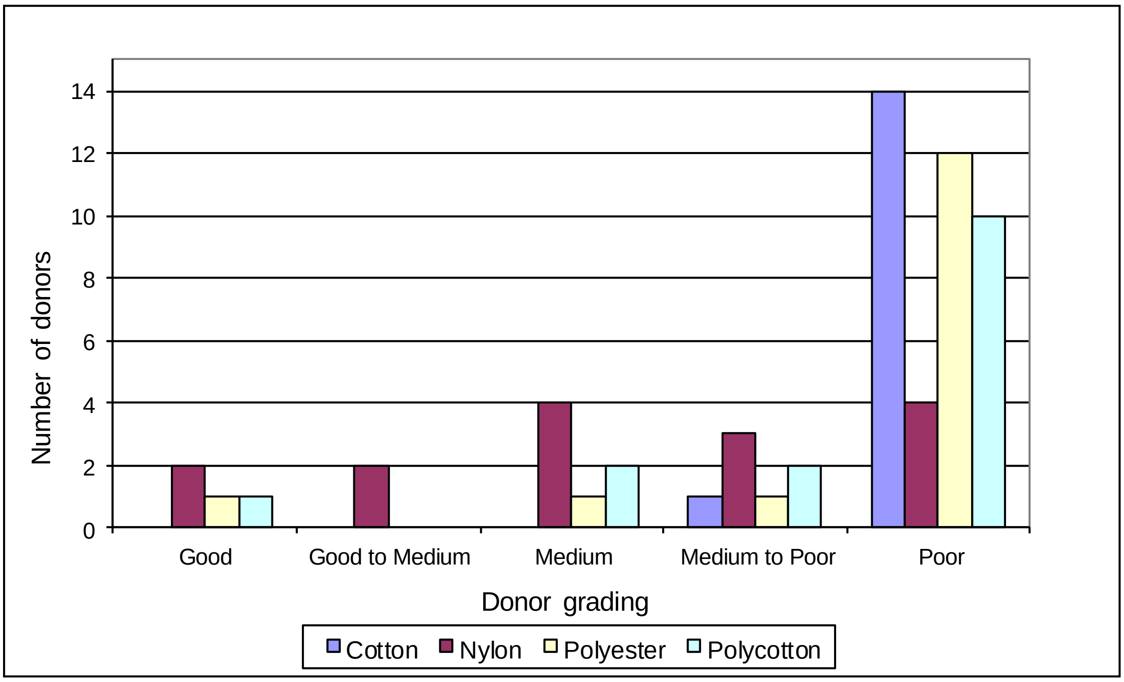


Figure 3.19: Combined donor grading of all donors in the study on each fabric type - cotton, nylon, polyester and polycotton, visualised with VMD. The grading ranged from poor to good depending on level of detail displayed in each sample processed. Gradings ranged from poor which showed little or no detail up to good with ridge detail and/or palmar flexion creases.

From the results [Figure 3.19] it can be seen that cotton is not a fabric that allows the VMD development of fingermark ridge detail as all the donors excepting one are classed as poor, with the other medium to poor (donor one, who is generally a good donor). Therefore the likelihood of recovering ridge detail is quite low though the area visualised may lead to an indication of a touch, which could be swabbed or taped for DNA, which in turn could lead to an identification. With nylon, it can be seen that the donors ranged from good to poor and it is this difference in donor grading between nylon and cotton, which highlights that a poor donor on one fabric can be a good donor on another (as exemplified by donor twenty). Overall, many of the donors were found to have a mixed ability depending on the fabrics used which is most likely due to the fabric surface and the levels of residues left thereon. In the case of cotton and nylon there were only five donors that were found to be poor on both fabrics.

Polyester also did not appear to allow ridge detail visualisation with the majority of donors (twelve) being rated as poor. Of the rest, one was good, one medium and one medium to poor rating and there was only one donor (donor one), who had a medium to poor rating for cotton and a good rating for nylon. With polycotton, ten of the donors were poor, with the rest rated as medium/poor to good - the good donor again being donor one.

The differences between the fabrics and the donor's ability to leave ridge detail could be due to certain fabrics allowing the fingerprint oils to evaporate more readily. Also/alternatively, the fabric is more absorbent and therefore the oil deposits from the donor's hands do not stay on the fabric's surface, which in turn could mean there will not be any interference as to where the gold and zinc is deposited during the VMD process. When comparing all the fabrics it appears that the smoother the surface the more readily ridge detail is observed. For example, nylon is the smoothest fabric and only four out of fifteen donors were rated as poor, compared to the roughest fabric (cotton) having fourteen donors rated as poor and only one as medium to poor.

3.19 Amount and quality of ridge detail visualisation

This comparison of all the donors and days for each fabric is shown in Figure 3.20 – 3.27]. It can be seen by comparing the bar charts for cotton [Figure 3.20 and 3.21] and nylon [Figure 3.22 and 3.23] that the nylon samples produced much more detail – eighty one nylon samples (graded higher than empty) compared to only three cotton samples meeting this criteria. With cotton these three donors were: donor one on day 1 graded as good and on day 14 as fair and donor two on day 1 with a fair grading. When this is compared to the nylon samples, it can be seen that there are many more samples ranging from fair to excellent and this amount of ridge detail could increase the possibility of identification.

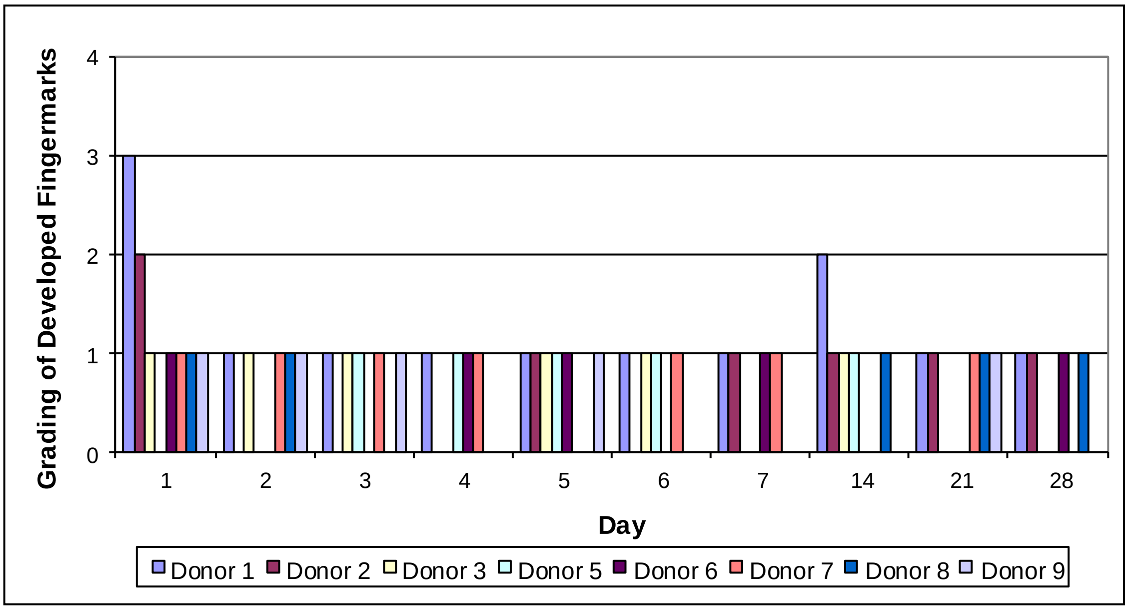


Figure 3.20: Cotton results showing fingermark grades (0 – 3) of each donor over the full timeline (days 1 - 7, 14, 21 and 28).

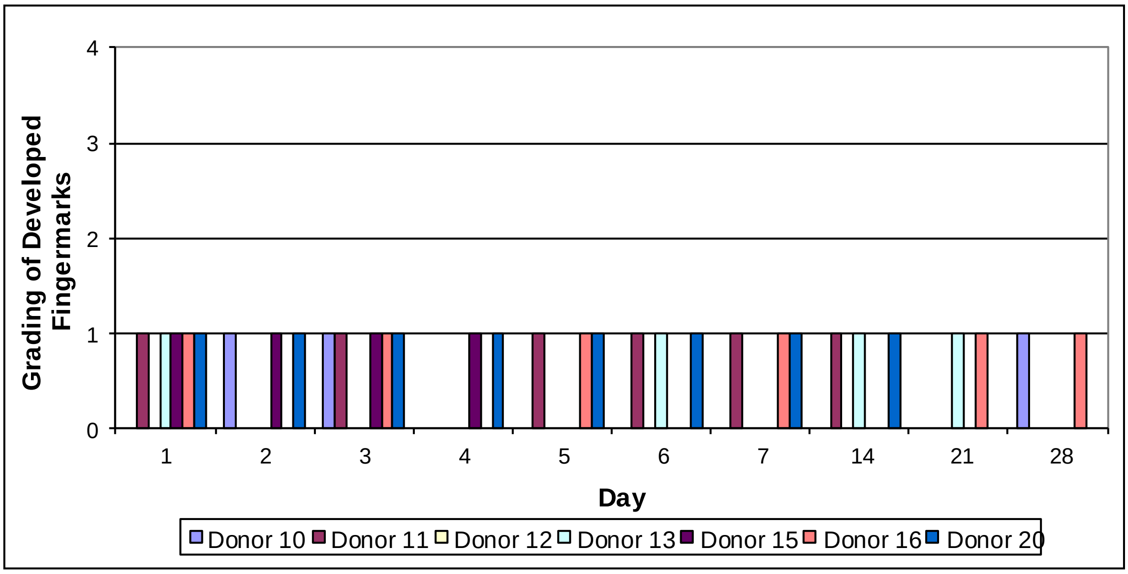


Figure 3.21: Cotton results showing fingermark grades (0 – 1) of each donor over the full timeline (days 1 - 7, 14, 21 and 28).

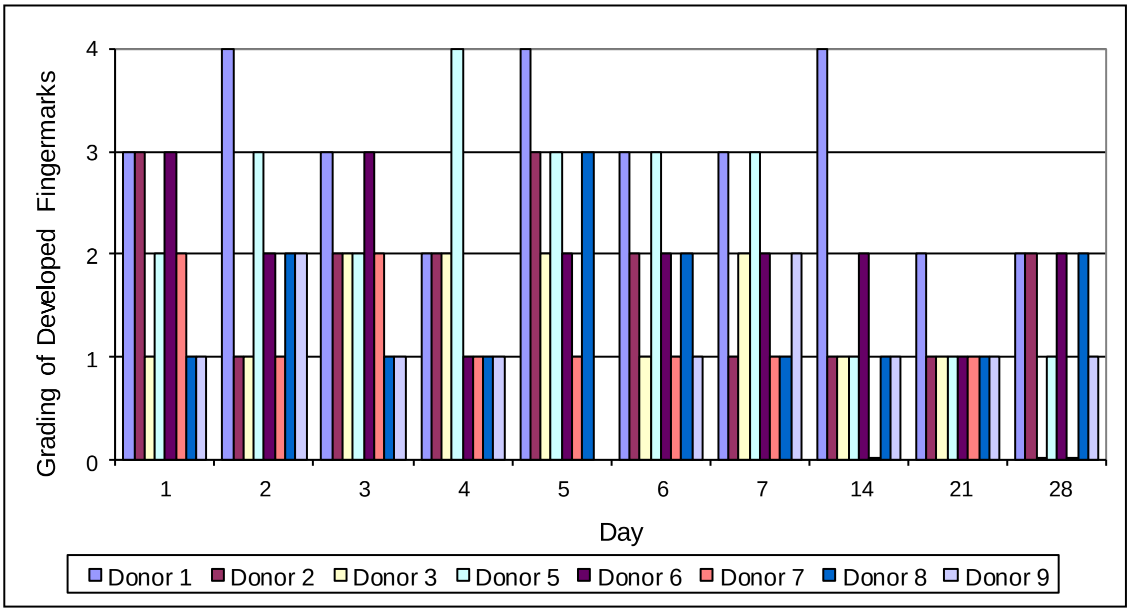


Figure 3.22: Nylon results showing fingermark grades (0 - 4) of each donor over the full timeline (days 1 - 7, 14, 21 and 28).

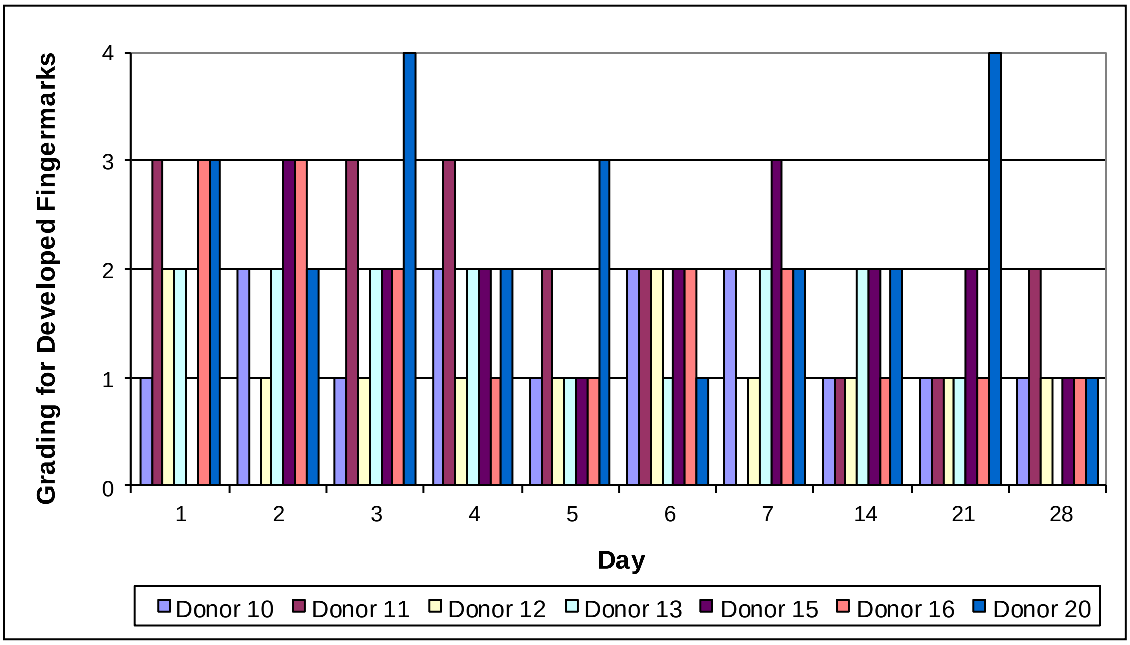


Figure 3.23: Nylon results showing fingermark grades (0 – 4) of each donor over the full timeline (days 1 - 7, 14, 21 and 28).

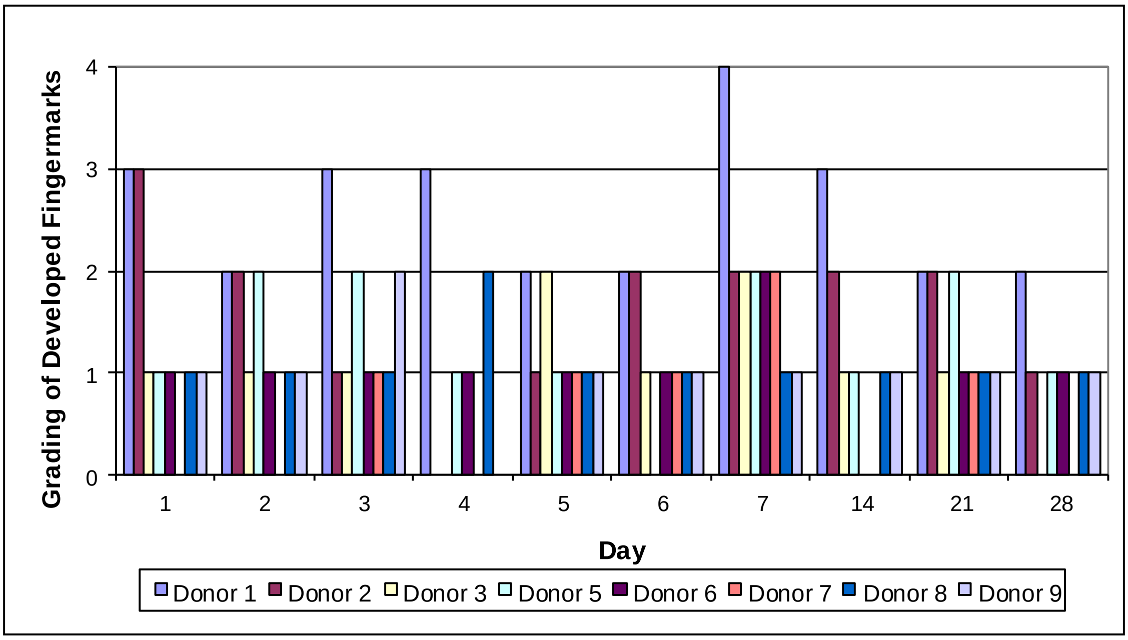


Figure 3.24: Polyester results showing fingermark grades (0 – 4) of each donor over the full timeline (days 1 - 7, 14, 21 and 28).

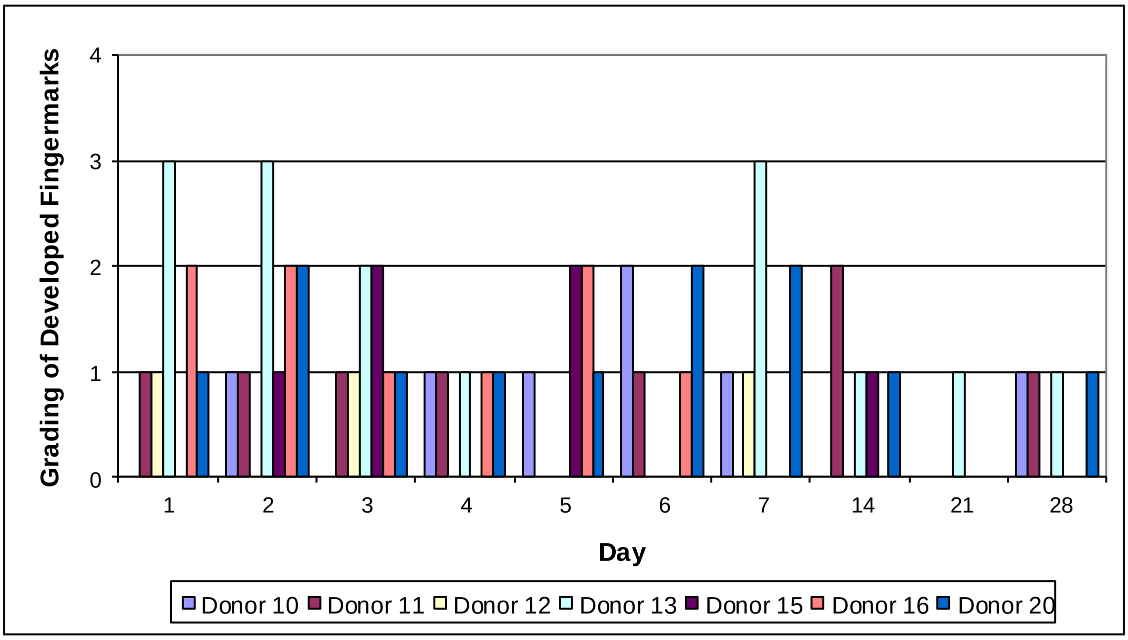


Figure 3.25: Polyester results showing fingermark grades (0 – 3) of each donor over the full timeline (days 1 - 7, 14, 21 and 28).

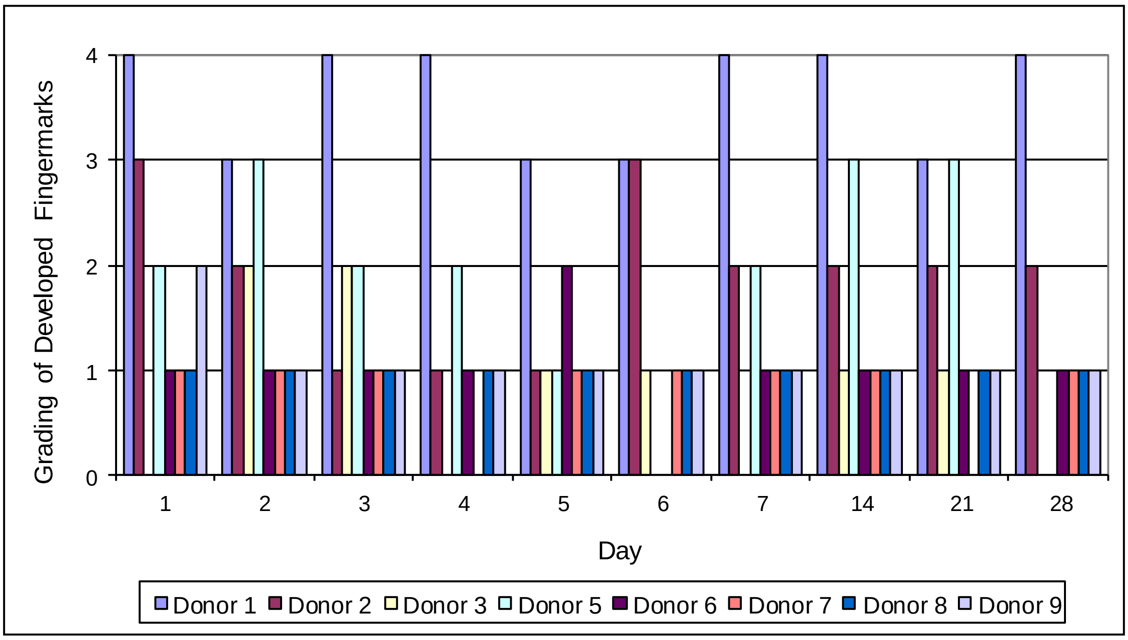


Figure 3.26: Polycotton results showing fingermark grades (0 – 4) of each donor over the full timeline (days 1 - 7, 14, 21 and 28).

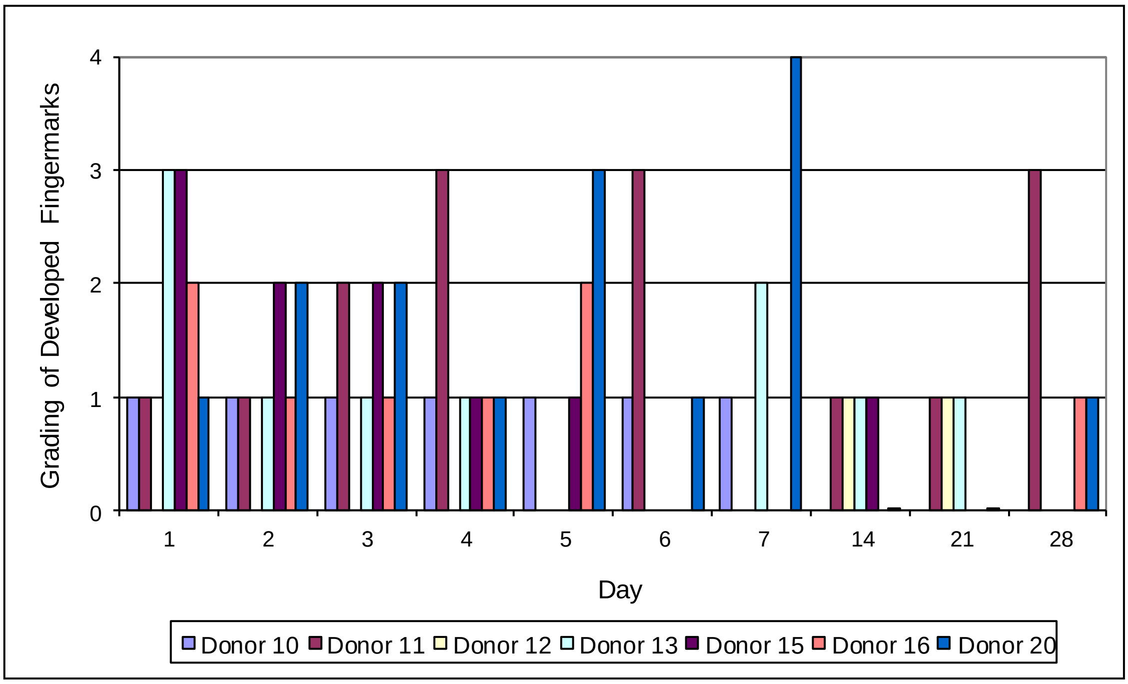


Figure 3.27: Polycotton results showing fingermark grades (0 – 4) of each donor over the full timeline (days 1 - 7, 14, 21 and 28).

Thus, nylon produced the highest donor fingermark ratings overall with the next highest level of detail being polycotton [Figure 3.26 and 3.27] and then polyester [Figure 3.24 and 3.25]. Polycotton does have more excellent donor ratings (7 compared to 6 for nylon), however, overall, nylon had more good and excellent ratings

(28) compared to polycotton (22) and polyester (9). Therefore, it can be seen that nylon had more samples with identifiable detail, and thus can be considered to be the fabric with the highest probability of acquiring a successful mark.

When considering all the fabrics there does not seem to be a pattern as to when is the best time to obtain the greatest amount of ridge detail. For example, with cotton all donors gave either empty or no development, with the exception of donor one and two who left a good and a fair sample on day 1 and donor one on day 14 leaving a fair sample [Figure 3.20]. This reinforces the idea that cotton has a poor ability to retain fingermark information. Donors on nylon are quite consistent in the detail they leave. For example, donor one left good to excellent marks from day 1 to 14 (with only one fair on day 4), only going down to a fair on days 21 and 28. Whereas donor seven only produced two fair samples on days 1 and 3, with the rest from days 4 – 7 being empty and days 21 and 28 being of no development. Both these donors have less detail in days 21 and 28; however donors two and twenty left fair and excellent detail on day 21.

When looking at polyester, again it is donor one that deposited the good to excellent ridge detail (days 1, 3, 4 and 7) with donor thirteen also leaving good ridge detail on days 1, 2 and 7. This high level of grading, thus detail was unusual for donor thirteen as they usually did not leave any more than a ridge detail grading of fair to empty and were generally classed as poor. This could be attributed to the donor doing something different, such as the food they had eaten or activity level, on these days, which allowed more deposits to be left and retained by the fabric.

With polycotton, it is again donor one who leaves the most ridge detail information (six excellent and four good ratings) followed by donor eleven with three good and donors two and twenty with two good ratings. In general, this fabric visualises target areas with the exception of poor donors on the later days, though it is still nylon that allows the more ridge detail to be seen.

Therefore these results demonstrate it is the donor and their ability rather than the type of fabric that is the most important when considering how much detail is left. The only conclusions that can be drawn about the amount of detail on each fabric is that with nylon and polycotton there will be more chance of finding some ridge detail. However, in a real case if a cotton or polyester article had been tested the day after the incident and the assailant was an extremely good donor some detail might be found.

3.20 Palmar flexion creases found on fabrics

Figure 3.28 demonstrates that all the fabric samples contained palmar flexion creases on all ten days and that there were more samples with palmar flexion creases than ridge detail. The amount of cotton samples with palmar flexion creases ranged from only one in a day (days 2, 3, 5, 7, 14 and 21) to three in a day (days 1 and 28). The amount of nylon samples with palmar flexion creases ranged from only three in a day (day 28) to eight in a day (day 3). With polyester there was a high of seven out of fifteen on day 7 to lows of two (days 3, 4 and 21) and one on day 28, whereas polycotton had six donors with marks on their samples for day 1 and 7 followed by five (days 2, 3 and 5) down to two on days 4 and 14. Though all the fabrics had swatches that contained marks there were no days where all the samples of all the fabrics were positive for palmar flexion creases. Overall, it was nylon again that showed the highest number of swatches positive for palmar flexion creases, followed by polycotton, polyester and cotton.

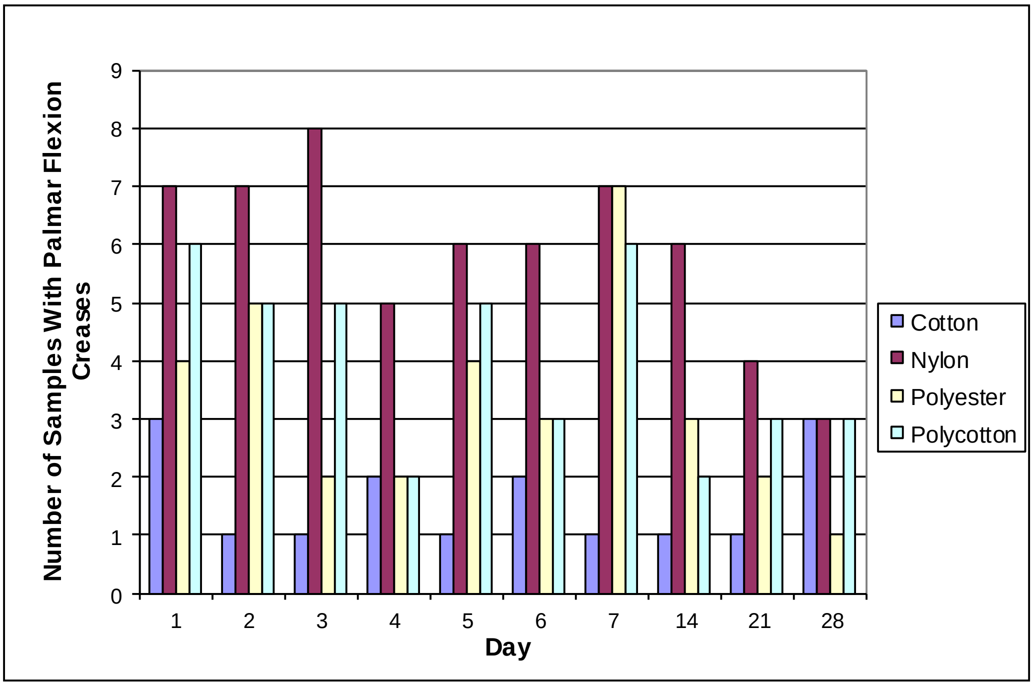


Figure 3.28: Overall number of cotton, nylon, polyester and polycotton samples from all donors over the whole timeline (days 1 – 7, 14, 21 and 28) which contained palmar flexion creases.

Over the last decade there has been much research carried out on the usefulness of palmar flexion creases and palm marks for identification purposes. Examples include, biometric identification for entry systems, fingerprinting databases – International Automated Fingerprint Identification System (IAFIS), National Automated

Fingerprint Identification System (NAFIS) (Nibouche, Jiang and Trundle 2012) and the British IDENT1 (SPSA 2006a, 2006b, 2007), as well as the differences between genetically identical individuals (Kong, Zhang and Lu 2006). Therefore, this shows that though palm marks are not always considered in relation to suspect identification, they can be used as identifiable markers, by use of the wrinkles, ridges and principal lines found on the palms. This is especially relevant when considering it has been stated "about 30 per cent of the latent marks recovered from crime scenes are from palms" (Jain and Feng 2009).

3.21 Ridge detail found on test fabrics

Figure 3.29 shows cotton only had one day (day 1) and one sample that displayed ridge detail, whereas nylon, polyester and polycotton showed such detail on all of the days except day 28 in the case of nylon and polyester. The nylon samples showed the most detail on days 1 and 2 with nine samples, hardly any on days 14 and 21 and none on day 28, which shows that the fresher samples (days 1 and 2) allowed more detail to be developed and that, in the case of nylon, detail declined as the samples aged.

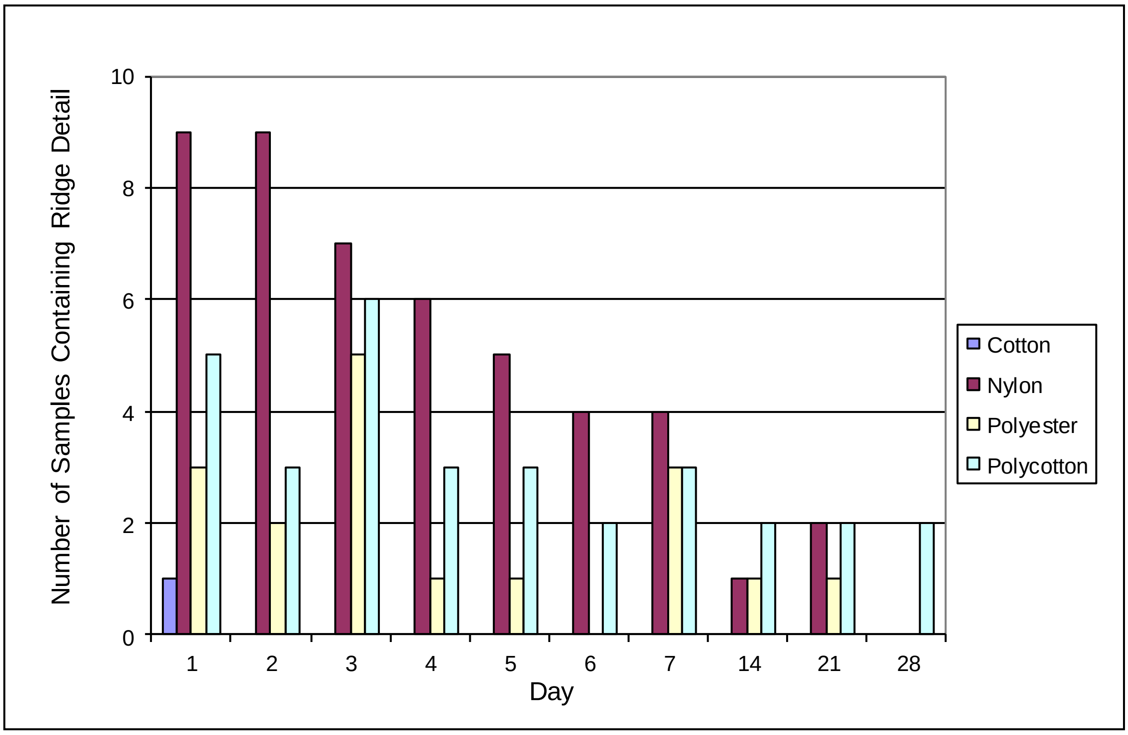


Figure 3.29: Overall number of cotton, nylon, polyester and polycotton samples from all donors over the whole timeline (days 1 – 7, 14, 21 and 28) which contained ridge detail.

The fact that the level of ridge detail left is due to the freshness of the samples is reinforced by the results from day 3 where seven nylon, five polyester and six polycotton donors all left some form of ridge detail. Also noteworthy is the observation that the number of donors leaving ridge detail reduces until day 21 when there are only two donors on nylon and polycotton and one donor on polyester that leave ridge detail and then on day 28 only two polycotton donors leaving ridge detail. All this indicates that the best fabric is nylon followed by polycotton when it comes to allowing the development of ridge detail by VMD. This could be explained by the weave structure and the ability of the fabrics to absorb residues. Both factors could make it more or less easy for the fabric to absorb the fingerprint residues or for them to evaporate from the fabric surface. Therefore if the residues are absorbed or evaporate then the VMD process will cover the fabric surface as there are no residues to stop the zinc adhering to the gold and therefore no fingerprint residues will be visualised. Thus the age of the samples does seem to have an effect on the level of detail visualised. When considering the fabric the more open the weave or the rougher the surface, the less ridge detail is visualised and conversely the tighter and/or smoother the weave the more detail is observed. This is illustrated when the order of most detail is considered; an average was calculated for each fabric type from the 150 samples (15 donors and 10 timeline samples). Nylon was the smoothest fabric with the most detail observed, giving an average grade of 1.72, then polycotton with 1.18, polyester with 1.08, while cotton only had 0.54. This may be expected as cotton was the roughest fabric, showed the least ridge detail, palmar flexion creases and even target areas. These results follow the same pattern as detailed in the 1993 study by Misner who determined that the fabric needed to have a smooth surface and a fine weave to allow detail to be visualised. Therefore, when considering the fabrics studied here and the smoothness of each one the order and amount of detail observed is not unexpected.

Operationally, the amount of ridge detail could possibly be improved by removing the samples from the VMD equipment, covering the areas of detail that need to be preserved and protected and then reprocessing.

3.22 Statistical analysis of fabric suitability for VMD fingermark visualisation.

The Kruskal-Wallis test was performed on data collated on the grades allocated to each of the samples and fabric types processed with VMD. This was carried out in an attempt to determine which of the fabric types would be most likely to allow the visualisation of the highest level of detail, therefore be most likley to lead to ridge detail and the possiblity of an identification. The null hypothesis (H_0) is that there is no difference between fabrics when the visualisation technique is VMD, and the alternative hypotheis (H_A) is that there is a difference. The hypothesis that is accepted is dependent on the p-value. If this value is <0.05 the H_0 is rejected and the H_A accepted and if the p-value is >0.05 then the opposite is the case.

As can be seen from Table 3.1 all of the fabric sets contained the same number of samples (150), however their mean ranks were quite different and therefore could be ranked in order of highest overall gradings. Nylon (401.95) being the fabric with the highest number of graded samples, followed by polycotton (310.60), polyester (294.55) and cotton (194.90) with the lowest number of graded samples. H_0 can therefore be rejected ($p<0.001$) and H_A accepted meaning there is a difference between the fabrics and therefore the level of detail that could be visualised on each of the fabrics This fabric order is the same as discussed in section 3.21 thus these results reinforce the opinion that the smoother tighter weave fabrics allow more viusalisation of ridge detail and therefore have a higher likelihood of leading to an identifcation.

Table 3.1: Kruskal-Wallis test using fabric as the grouping variable to compare grades produced in the four fabrics (cotton, nylon, polyester and polycotton) visualised using VMD. Results show the number of each samples in each fabric set, the mean rank of each fabric set, the Kruskal-Wallis value, degrees of freedom and p-value.

Fabric Type	Number	Mean Rank	Kruskal-Wallis Value	Degrees of Freedom	p-value
Cotton	150	194.90	123.112	3	<0.001
Nylon	150	401.95			
Polyester	150	294.55			
Polycotton	150	310.60			

3.23 Target areas for DNA on test fabrics

The ability of the fabrics to allow an individual to leave a target area on a fabric, which could be tested for DNA, is shown in Figure 3.30. It can clearly be seen that even though all materials have target areas every day, it is nylon that shows the most with six of the days (days 2, 3, 4, 6, 7 and 21) when all of the donors left target areas. The lowest number of donors to leave target areas is on day 28 but still 80 % of the donors tested left a target area.

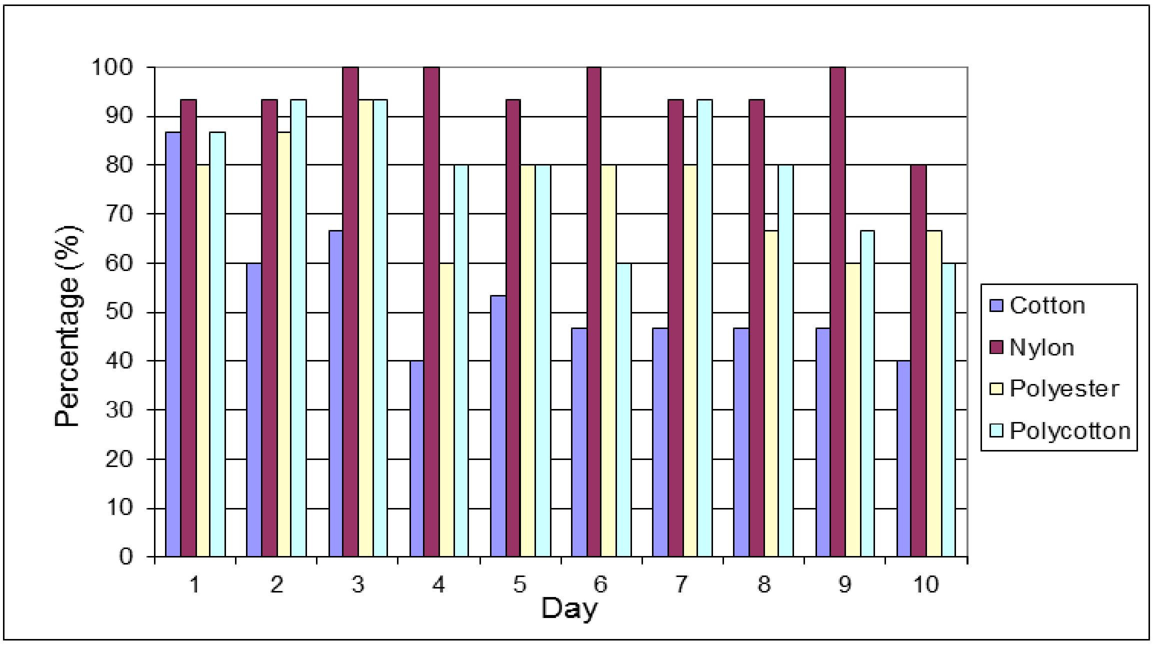


Figure 3.30: Overall percentage of cotton, nylon, polyester and polycotton samples from all donors over the whole timeline (days 1 – 7, 14, 21 and 28) which contained target areas.

The highest number of donors to leave target areas on cotton was on day 1 (86 %), but this falls to 60 % by day 2 and generally decreases to a minimum of 40 % (day 28). This information again reinforces the opinion that nylon is a more effective fabric from which to recover information about the individual, be that DNA or fingermark detail and that it constantly gives more information than cotton.

Neither polyester nor polycotton have a 100 % day, though both have days were fourteen (93 %) donors produced a target area – polyester on day 3 and polycotton on days 2 and 3. The rest of the days ranged from a low of 60 % (polyester days 4 and 21 and polycotton day 28) to a high of 87 % (polyester day 2 and polycotton day 1).

In conclusion, of the fabrics utilised in this study nylon demonstrates a better ability to retain fingerprint residues and therefore allow more ridge detail to be developed through VMD. However, all the fabrics have the propensity to allow development of impressions, from small fingertip to full grabs that could be utilised as target areas for DNA.

3.24 Visualisation of samples by means other than photography

It was found that ridge detail that could be seen on samples by the naked eye was not reproduced when photographed, due to the fabric weave interfering or disguising the mark. The use of fast Fourier transform (FFT) did lead to improved contrast between the fabric and the ridge detail, thus allowing some to be more easily seen. Paul Deacon (2012. pers. comm., 5 December) carried out some FFT work on samples produced in this study and this showed a reduction in the background patterns caused by the fabric weave, enabling more ridge detail to be viewed which made it easier to see and determine the ridges and thus aid in identification. For example, Figure 3.31 and 3.32 show swatches with clear hand grabs. However the photographs on the left hand side of both, were taken with a Nikon D50 camera under normal white lighting and no real ridge detail can be observed in the fingertips even though it could be seen by the naked eye [Figure 3.31 was graded as a 4 and Figure 3.32 a grade 3]. The right hand side photographs in each figure shows improvement after using a Nikon D300 camera and a FFT software package and in Figure 3.31, ridge detail in all the fingers can clearly be seen, whereas in the original photograph the fingers look empty. Figure 3.32 shows the same improvement in that the flexion creases on the palm and fingers as well as in the fingertip. The use of FFT led to increased ridge detail in many of the samples tested. However, these samples were not regraded in the main study as they were only a small selection and not all the other samples had FFT performed on them and therefore were not regraded, thus the inclusion of this new data may have led to the overall results becoming skewed.

This is reinforced by the work carried out in conjunction with Jen Raymond of the NSW Police during a visit to Australia (2010. pers. comm., 30 August), here three different fabric types (pink polyester, black and white striped satin and brown cotton) had marks planted and were processed with gold + zinc VMD.

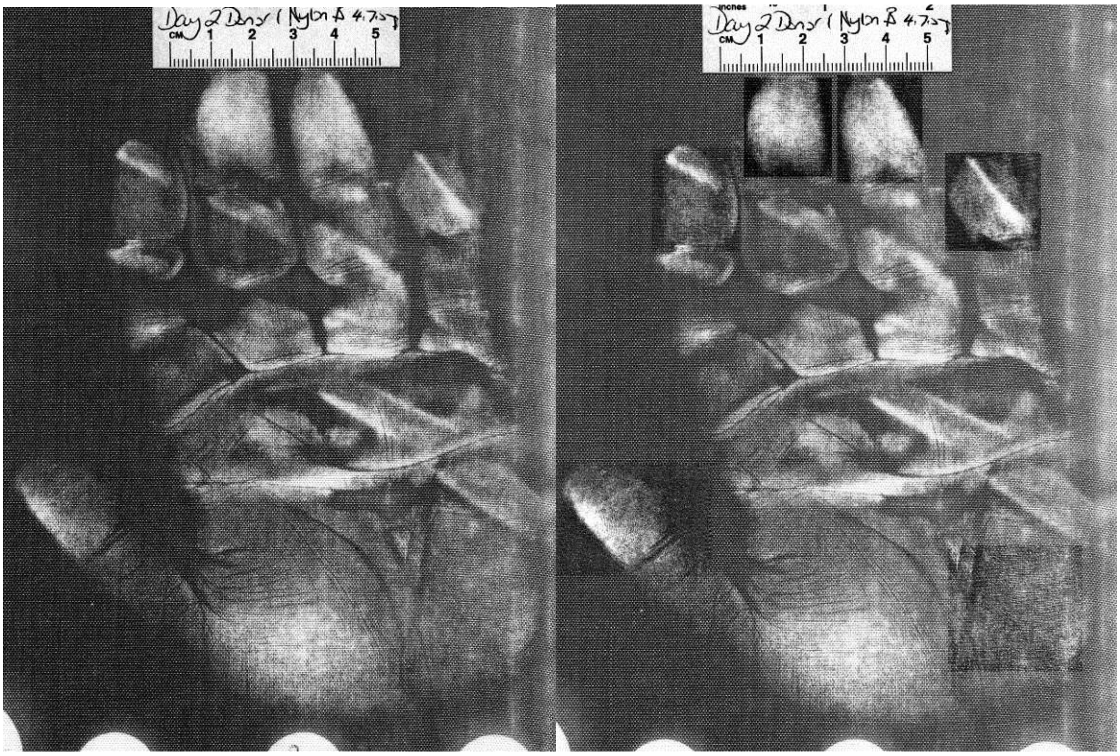


Figure 3.31: Day 2, donor one, nylon VMD visualised swatch. Image on left taken with Nikon D50 – palmar flexion creases visible, though all marks are empty. Image on right after FFT – ridge detail can now be seen in the fingertips (Deacon 2013a).

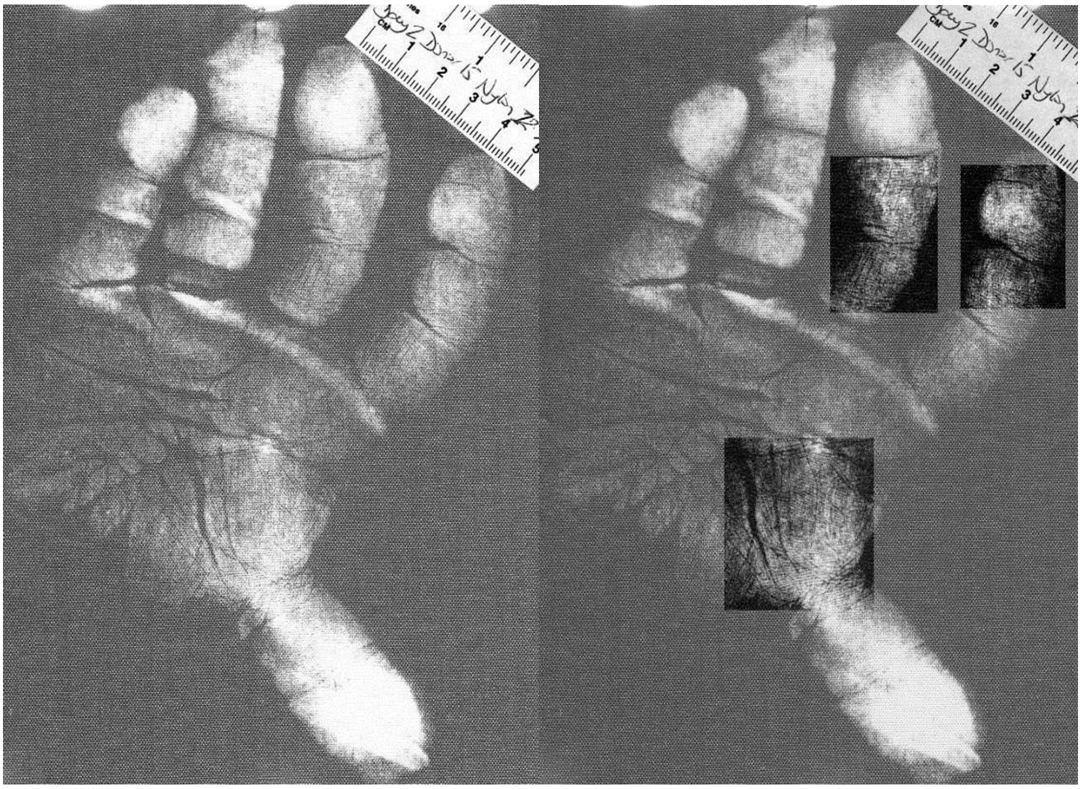


Figure 3.32: Day 2, donor fifteen, nylon VMD visualised swatch. Image on left taken with Nikon D50 – showing limited ridge detail. Image on right after FFT – showing enhanced ridge detail in palm and on fingers (Deacon 2013b).

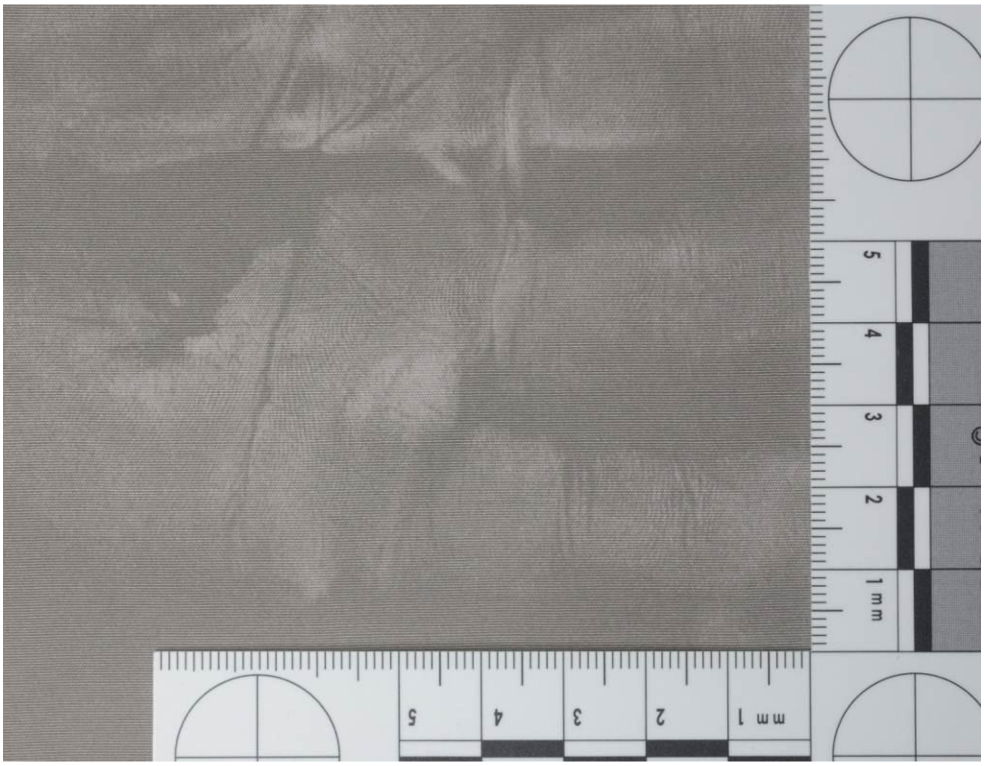


Figure 3.33: Pink polyester fabric grab sample visualised using VMD and photographed under white light, showing only a faint grab and limited detail (Raymond 2010a).

On the processed swatches, varying levels of detail were observed, but again less was seen in the photographs than by the naked eye. With the pink polyester it was found that small reflections on the surface of the fabric made it difficult to visualise the ridge detail [Figure 3.33]. Consequently, cross-polarised light was investigated where a circular polarising filter on the light source and lens was rotated until the reflections disappeared. This made the ridges easier to see due to less interference from the fabric weave [Figure 3.34]. FFT was also used, which further improved the ridge detail that could be observed [Figure 3.35] as there was even less interference from the weave.

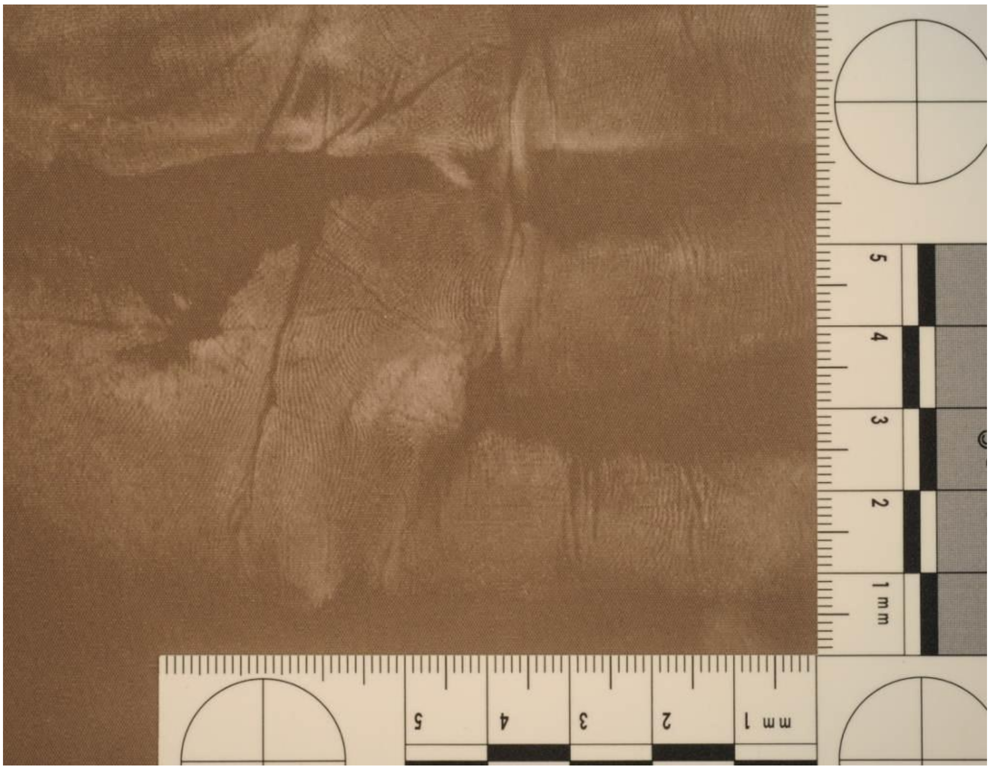


Figure 3.34: The same pink polyester fabric grab as in figure 3.33 photographed using cross-polarised lights, shows a clearer and more obvious grab (Raymond 2010b).

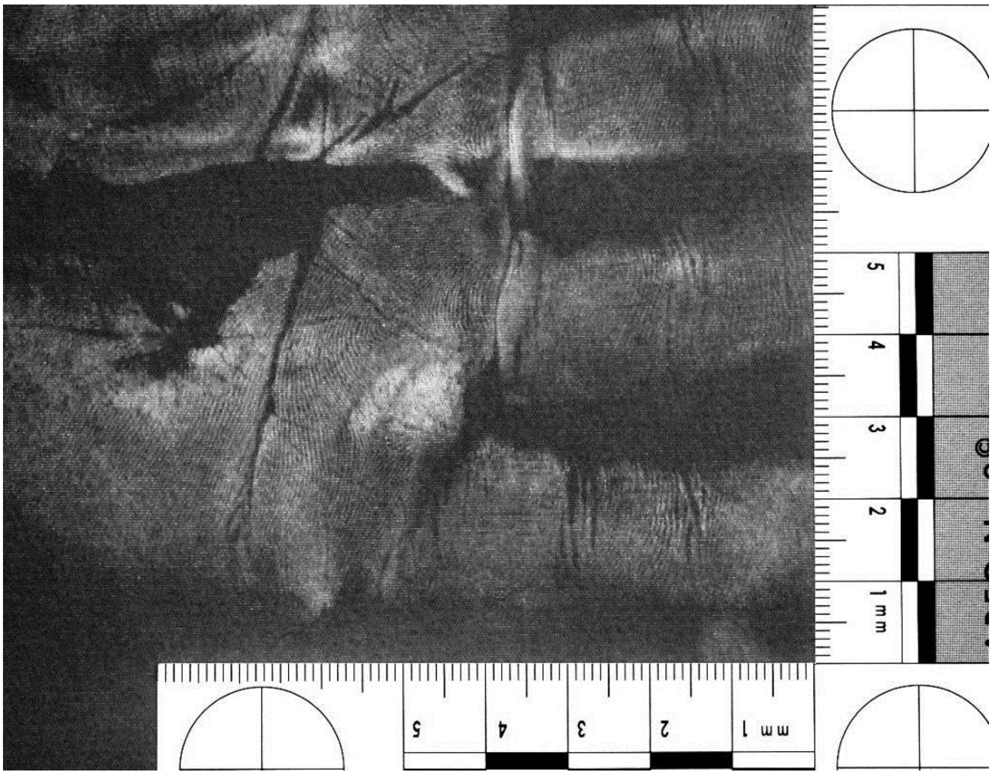


Figure 3.35: The same pink polyester fabric grab from figure 3.33 showing further enhancement by photographing using a FFT filter. Both the hand and ridge detail is more obvious with FFT than with either white or cross-polarised light (Raymond 2010c).

When black and white satin was viewed with white light there was the compounding factors of two different colours as well as the fabric weave and reflections, therefore it was difficult to see any ridge detail. This was improved slightly by the use of a shift lens and a diffuse white light box or specular light held beside the lens and the use of FFT improved it a little more by removing more of the fabric weave. However it was the use of infra-red light that led to the greatest improvement; here tungsten lighting was shone on the sample and photographed with an IR blocking filter removed and an IR pass filter fitted on the lens of the camera. With the use of IR the fabric pattern was completely removed, however some interference from the fabric weave could still be seen, which still interfered with the visualisation of the ridge detail. The use of all these techniques aided in the improvement of the recorded ridge detail, which in turn could help in the interpretation of the marks, and, hence, a successful identification of an individual. The above methods of enhancement involved the use of different photography and lighting conditions; however a simpler method of improving the marks further was demonstrated on the satin. This involved the VMD developed marks being treated with magnetic black powder, then tape and gel lifts were used to remove the marks from the fabric. As they were no longer sitting on the surface of the fabric, but on a clear and un-patterned surface, there was no longer an issue in terms of the fabric weave obscuring the ridge detail.

The VMD development of the brown cotton fabric was less successful than the other fabrics and the original image did not show much of detail; however it was determined that something as simple as changing the background upon which the swatch is photographed could improve the detail observed. This is illustrated in Figure 3.36 and 3.37 where cross polarised light was used to take photographs on both a white and a black background. It was determined that the black background was the more effective and this was further enhanced with inverse FFT [Figure 3.38] allowing palmar flexion creases to be more clearly seen, along with flexion creases on the fingers. Though the fingertips are still empty this new information could at the least include or exclude an individual as a suspect in a case.

Figure 3.36: Brown cotton fabric grab sample visualised using VMD photographed with white light on white background, showing an extremely faint hand mark with little detail (Raymond 2010d).

Figure 3.37: Brown cotton fabric grab sample visualised using VMD photographed with white light on black background. Here the hand became a little more obvious with the introduction of a darker background (Raymond 2010e).

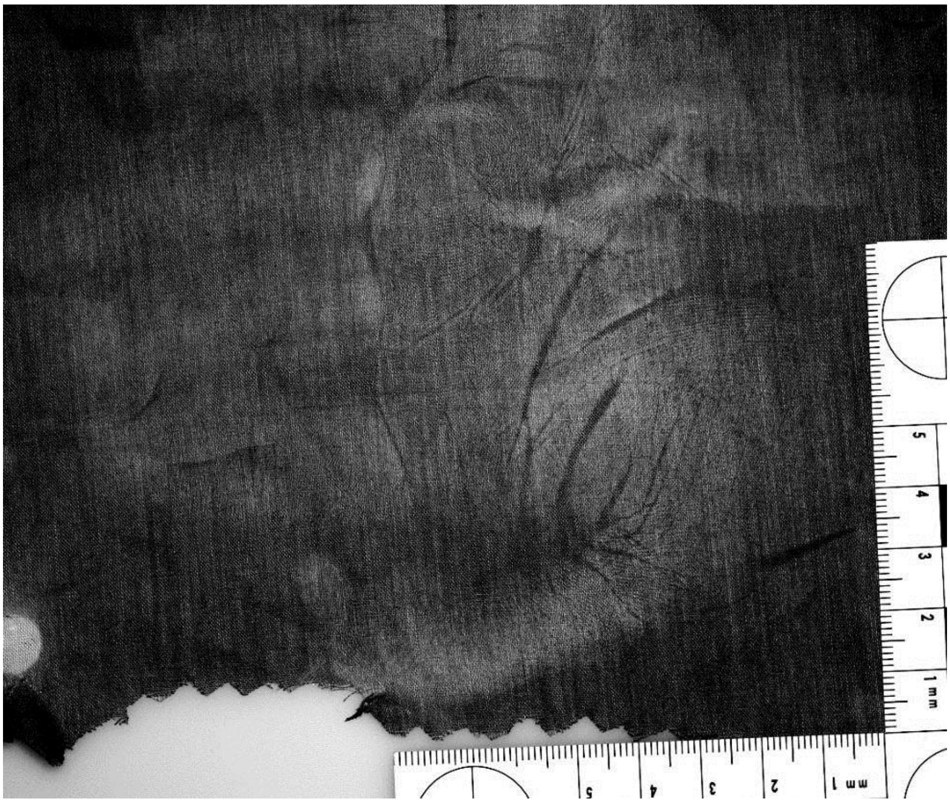


Figure 3.38: Brown cotton grab sample visualised using VMD photographed with white light on black background after inverse FFT. This combination of coloured background and FFT led to a more obvious hand mark with clearer ridge detail (Raymond 2010f).

3.25 Conclusion

When considering all the fabrics it seems that it is the less porous and smoother fabrics with the tighter weave that display the most ridge detail. For example, compare nylon to the fabrics with a rougher and/or more porous surface which only seemed to display empty pints or grab outlines. However, even though these marks may not help with identification through ridge detail they could be used to target for DNA, rather than taping or swabbing the whole article or for a way of corroborating or refuting the sequence of events. There is an issue of the fabric weave obscuring or interfering with the level of ridge detail that can be recorded photographically, however the use of FFT or IR photography seems to be a way of combating this problem. Therefore, in future work a digital camera system (DCS), such as those regularly used by the forensic police laboratories, must be used to record and enhance the images. Thus, enhancement, such as that produced by FFT could be used to increase the level of detail observed as well as reduce the background interference from the fabric weave and this higher level of detail would lead to a greater chance of identification. As this technique was not used in the main study the impact cannot be determined as to the full effect the use of FFT could have had on the final grades of each mark, however it could be suggested that many of the marks would have resulted in a higher grade.

The age of the sample does seem to impact on the level of detail visualised by the VMD process, so it would be advantageous to process items as soon as possible after acquisition in order to optimise the amount of detail visualised. Therefore if an individual reports an assault within the first few days, there may be a higher chance of visualising ridged detail. The report by Kelly, Lovett and Regan in 2005 states that in most cases if an individual is going to be report an assault they generally do so within the first few days. Thus it is likely that with a suitable fabric, ridge detail may be observed, however even if the article is not processed quickly this study has also demonstrated that older samples can contain ridge detail or palmar flexion creases as well as showing areas from which to collect DNA samples.

The biggest factor regarding whether ridge detail is, or is not, observed is the donor. A good donor can regularly provide excellent marks in the form of ridge detail in the fingertips, on the palms, as well as visible areas to swab for DNA. While poor donors do not leave good detail, which may be due to their drier skin and consequently having lower levels of residues, which in turn would not allow for as high a level of detail, however there is still the possibility of collection of DNA and an identification via a DNA profile.

Therefore, VMD should be considered as a useful tool in the identification of ridge detail in the fingertips and palms as well as visualising areas to target for DNA collection, all of which could aid in the identification of assailants from victim’s clothing.

4. VISUALISATION OF FINGERMARKS ON FABRIC SAMPLES BY MEANS OF CYANOACRYLATE FUMING (CAF)

4.1 Aims

To use CAF in order to determine the level of fingermark and palm ridge detail on fabrics and to discover the quality of marks visualised on cotton, nylon, polyester and polycotton and determine the variability between fifteen donors and the effect of ageing the samples over a 28 days.

4.2 Donor one

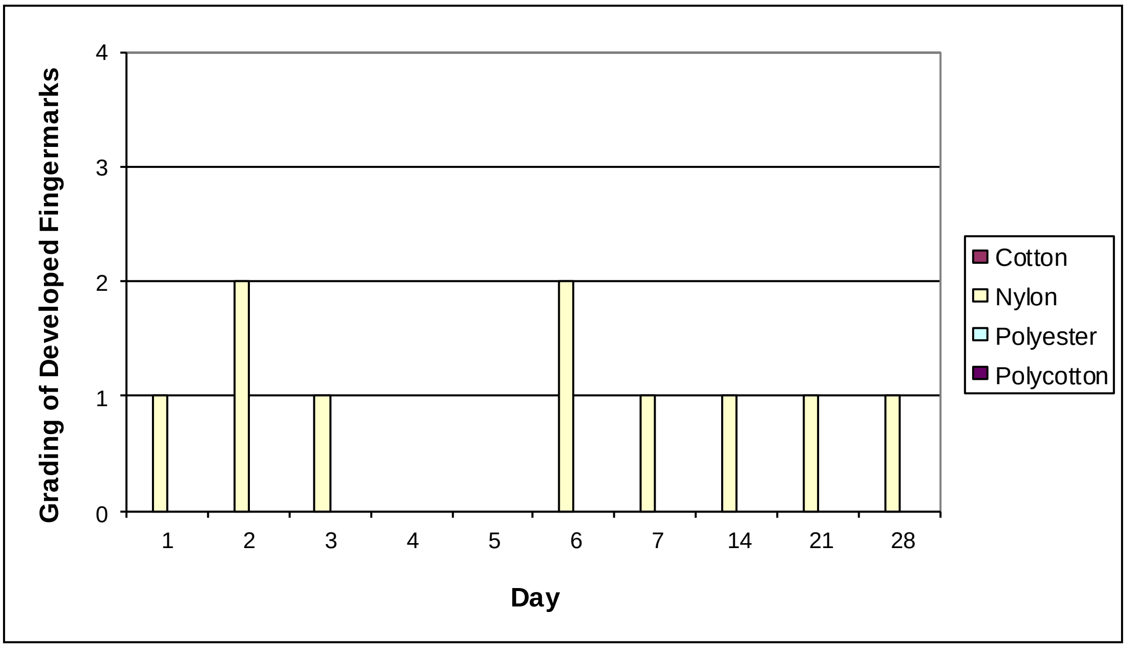


Figure 4.1: Grades of fingermarks (0 – 2) for donor one over the 10 day timeline (days 1 – 7, 14, 21 and 28) on cotton, nylon, polyester and polycotton, visualised with CAF.

Figure 4.1 shows that donor one had a poor rating for nylon, cotton, polyester and polycotton due to the lack of any target areas on all samples except day 7 polyester [Figure 4.2] and this sample only had the possibility of a fingertip impression. Therefore, each of these fabrics had an overall fingermark grading of 0. Though nylon also achieved a poor donor rating as all but two samples (days 4 and 5) displaying target areas - these ranged from a faint hand grab (grade 1) to full grab with palmar flexion creases (grade 2)[Figure 4.3]. This resulted in nylon achieving an overall grading of 1 and, though none of the samples showed any ridge detail, four of them (days 2, 6, 21 and 28) contained palmar flexion creases therefore these could possibly help in identification.

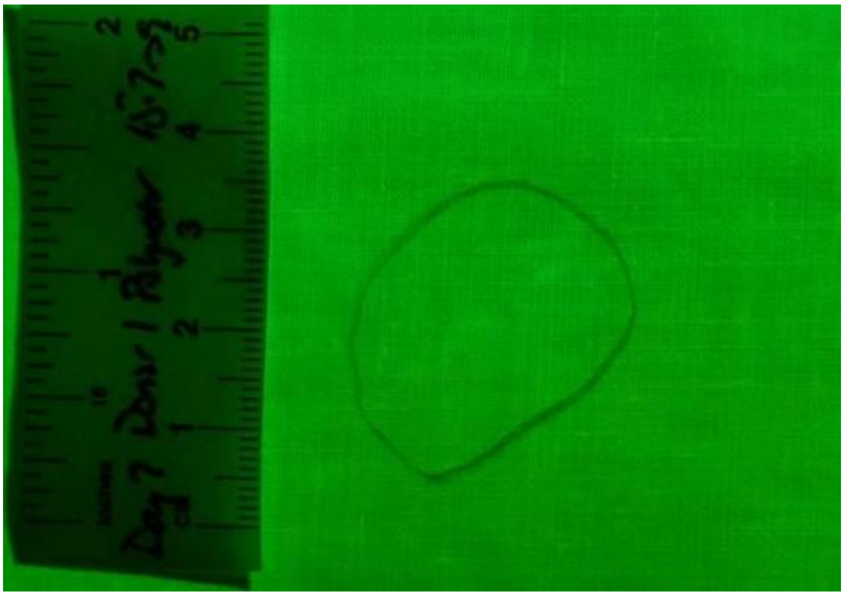


Figure 4.2: Possible fingertip mark on donor one, day 7, polyester fabric sample, visualised with CAF/BY40, photographed with a Nikon D40, a yellow (476nm) filter and blue Crime lite (420 - 470nm).

Overall, this donor did not leave successful marks – 80 % were graded as 0 with only 15 % grade 1 and two samples (5 %) graded as 2. When considering DNA collection, eight out of ten nylon samples had grabs that could be used as target areas for DNA and though it was not determined, in this work; whether the CAF would interfere with DNA collection several reports have indicated that this is not problematical. In both the Lee and Gaensslen (2001) and Ramotowski (2013) editions of "Advances in Fingerprint Technology" it is stated that the person examining an article used to have to decide whether the DNA or the mark was the most important, as DNA analyses used to be effected by CAF, but with the advances that have been made in DNA processing it is no longer necessary as less of the chemical fingerprinting techniques "inhibit sample analyses" (Lee and Gaensslen 2001, p: 91) and that extremely small amounts of DNA have been collected and processed. This is reinforced by the comments in the papers of Bille, Cromartie and Farr (2009) and Wickenheiser and Challoner [no date] who indicate that the use of CAF still allowed for full DNA profiling and the fuming process may actually help by causing the cells and, thus DNA, to be secured to the item. Wickenheiser and Challoner (1999, p:3) hypothesised that the cyanoacrylate (CA) covered the skin cells and kept them on the item until they are collected later by swabbing or taping, therefore making CAF a "non-DNA-destructive" technique.

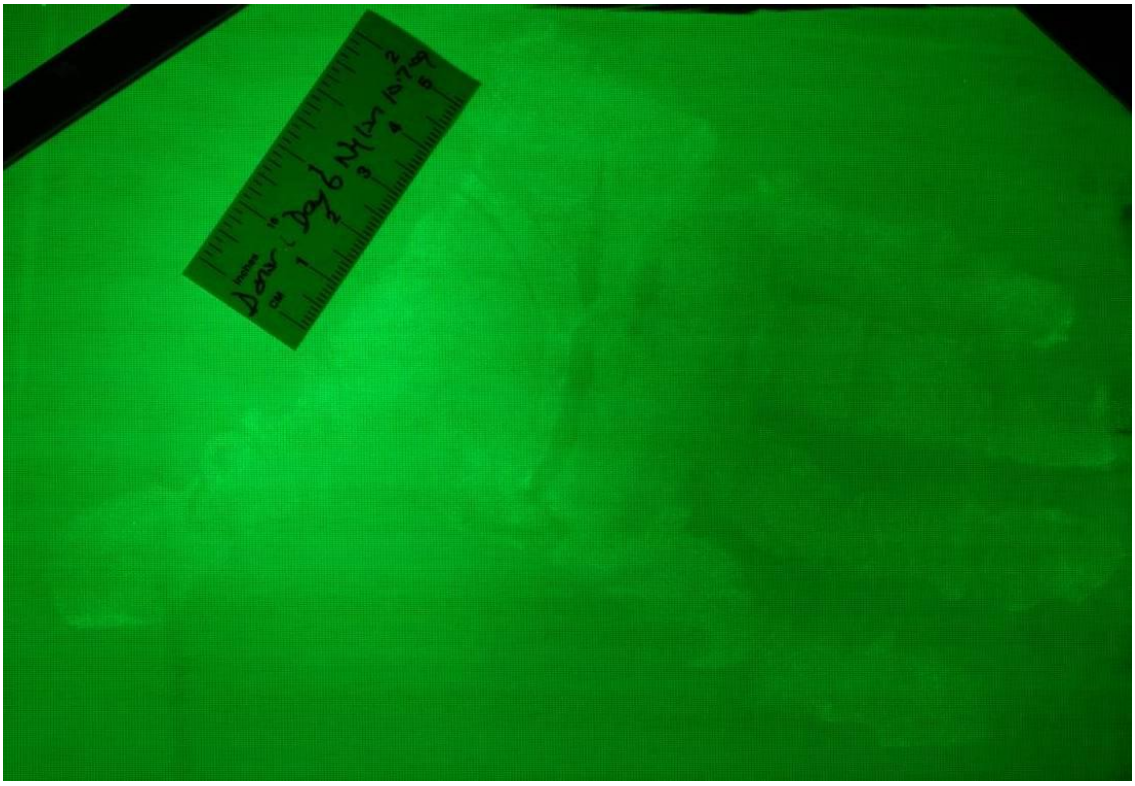


Figure 4.3: Full hand grab demonstrating palm lines and empty marks on donor one, day 6, nylon sample, visualised with CAF/BY40, photographed with a Nikon D40, a yellow (476nm) filter and blue Crime lite (420 - 470nm).

4.3 Donor two

Donor two also had poor ratings for cotton, polycotton and polyester with all samples having no development or target areas [Figure 4.4], with the exception of day 7, polyester having a possibility of a fingertip impression. Therefore each of these fabrics has overall gradings of 0. The overall nylon rating was also poor however there were four fair ratings (days 1, 6, 7 and 14, all grade 2), five empty ratings (days 2, 3, 5, 21 and 28, all grade 1) and one no development rating (day 4). This gave nylon an overall fingermark grading of 1.3, though again none of the samples produced ridge detail that could help in identification. This low overall grade is due to the high percentage (65 %) of grade 0 samples and only 23 % for grade 1 samples. However, days 1 [Figure 4.5], 6, 7, 14 and possibly 5, had palmar flexion creases (13 % of all swatches) that could help in identification. Thus, all days, except 4, had target areas these could be taped for DNA.

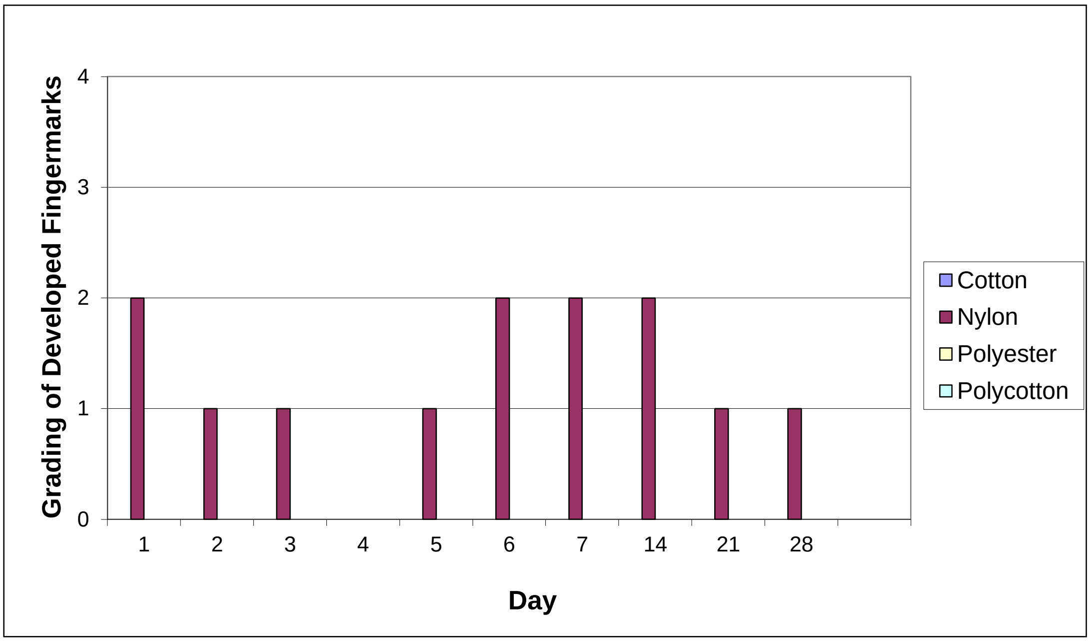


Figure 4.4: Grades of fingermarks (0 – 2) for donor two over the 10 day timeline (days 1 – 7, 14, 21 and 28) on cotton, nylon, polyester and polycotton, visualised with CAF.

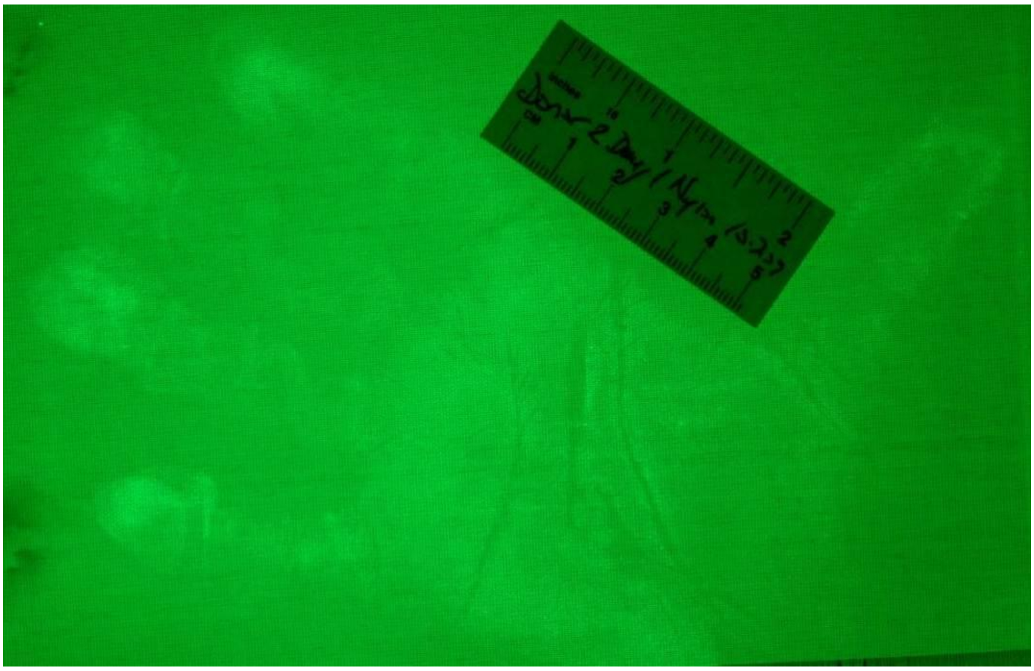


Figure 4.5: Full hand grab demonstrating palm lines and empty marks on donor two, day 1, nylon sample, visualised with CAF/BY40, photographed with a Nikon D40, a yellow (476nm) filter and blue Crime lite (420 - 470nm).

4.4 Donor three

With donor three, there was a lack of development and target areas so their donor rating was poor with an overall grading of 0 for cotton, polycotton and polyester. However, this time there were two days, 7 and 28, that produced the possibility of target areas in the form of thumb and fingertip marks on polyester. The nylon rating for this donor was also poor, however with this fabric day 2 had a fair rating (grade 2), four days were empty (days 6, 7, 21 and 28, grade 1) and there was four no development ratings (days 1, 3, 4 and 14, grade 0). Nevertheless, all these days have the possibility of target areas and only one day (5) with no development at all. This does of course mean that for nylon with an overall fingermark grading of 0.6 there are no fingermark details that could help lead to an identification. This is reinforced by the overall percentages – grade 0 (87 %), grade 1 (10 %) and grade 2 (3 %).

4.5 Donor five

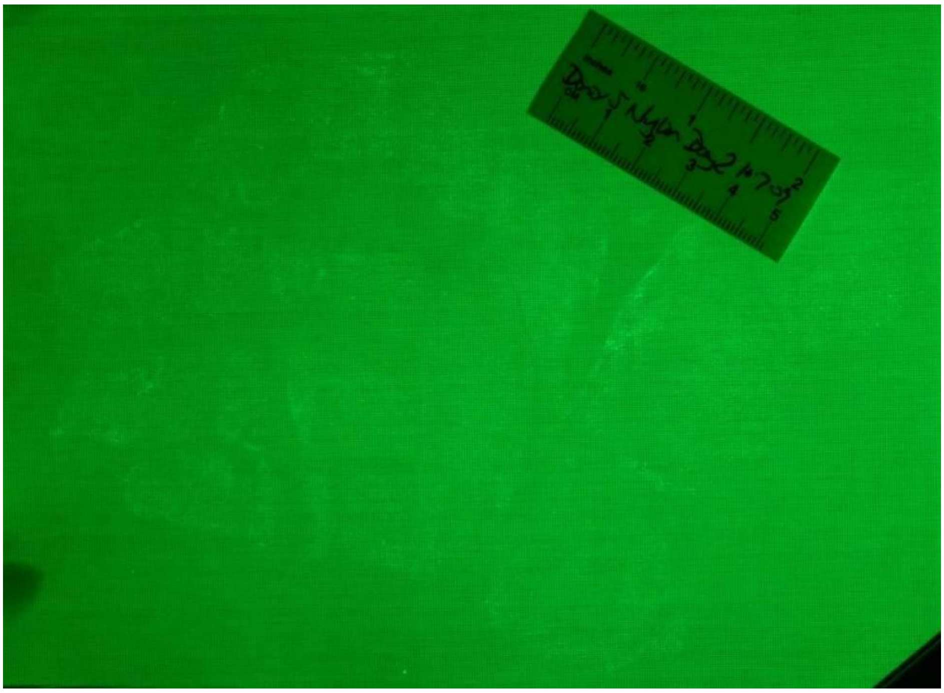


Figure 4.6: Faint hand grab with empty marks and possible palm lines on donor five, day 2, nylon sample, visualised with CAF/BY40, photographed with a Nikon D40, a yellow (476nm) filter and blue Crime lite (420 - 470nm).

Donor five had one polyester sample, on day 5, that showed a possibility of a fingertip and palm mark, however both cotton and polycotton showed no development and therefore this donor was rated as poor and had an overall grading of 0 for each fabric type. The nylon samples were rated as poor and had an overall fingermark grading of 0.8, due to lack of identifying detail with two no development (days 5 and 28, grade 0) with one having a possible target area and all the others (days 1, 2 [Figure 4.6], 3, 4, 6, 7, 14 and 21, grade 1) being empty. The empty samples ranged from full grab with possible palmar flexion creases to extremely faint grabs and of these samples, nine could be taped for the collection of DNA. Ridge detail identification is not possible with these samples, as 80 % had a grade 0 and 20 % a grade 1.

4.6 Donor six

Donor six had one polyester sample (day 7) with a possible palm mark, while cotton and polycotton produced no development and therefore a poor donor rating and overall grade of 0 for each of these fabric types. The nylon rating was also poor due to only three samples out of ten having a rating other than no development (days 2, 5 and 14, grade 1), thus grades of 1 and an overall fingermark grading of 0.3. However, of the remaining seven there were no development samples, three had the possibility of producing a target area for DNA collection. With these samples there is not much chance of identification as 92 % were grade 0 and only 8 % grade 1. Of these grade 1 samples only day 5 had palmar flexion creases and none had any ridge detail.

4.7 Donor seven

Donor seven had a poor rating for all four fabrics, due to there being very few observable marks, none on cotton or polycotton and only seven marks on the nylon and polyester swatches. For polyester, the only positive mark was day 5, with this sample having the possibility of fingertip and thumb impressions. Nylon had one empty grade 1 rating (day 2) which was a faint grab, while days 1, 5, 6, 7 and 14 have the possibility of fingertip and palmar flexion creases, so were graded as 0, which led to an overall fingermark grade of 0.1. Thus, this donor has little chance of identification via ridge detail due to 97 % of the swatches being graded as 0 and only 3 % having a grade of 1.

4.8 Donor eight

Donor eight also had a poor rating for all four fabrics due to lack of any development. Cotton produced a possible mark of the donor’s thumb, palm and fingertip on day 3, but was graded as 0 for all days. Nylon on the other hand was still poor for the donor rating, as most of the samples were grade 0 (92 %) and the rest were grade 1 (8 %). These grade 1 empty ratings (days 7, 14 and 28) were faint grabs and fingertip marks but had no ridge detail. As nylon had the only positive samples, the overall fingermark grading was 0.3 for nylon, with 0 for cotton, polyester and polycotton.

4.9 Donor nine

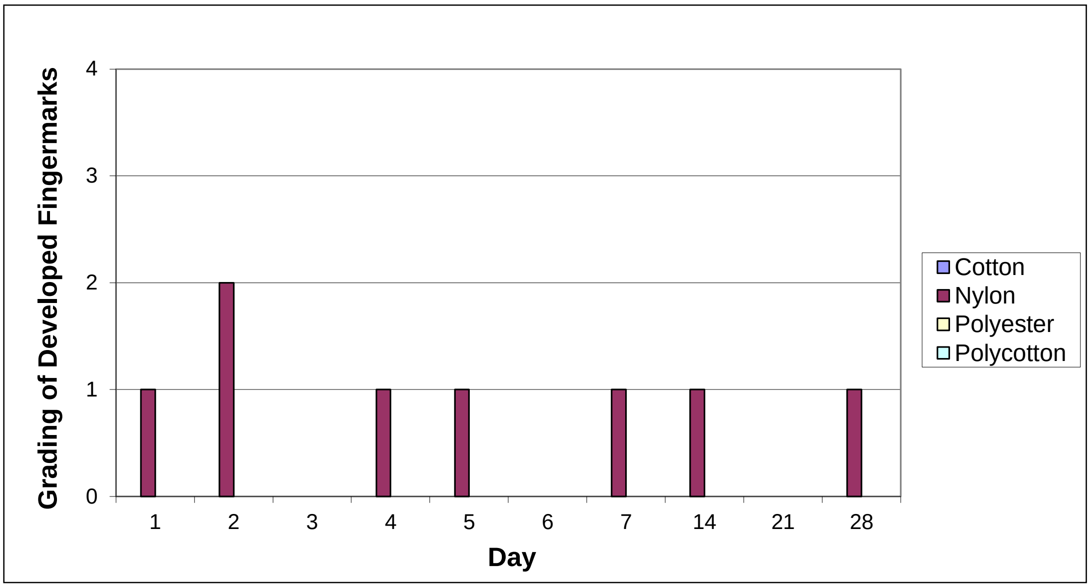


Figure 4.7: Grades of fingermarks (0 – 2) for donor nine over the 10 day timeline (days 1 – 7, 14, 21 and 28) on cotton, nylon, polyester and polycotton, visualised with CAF.

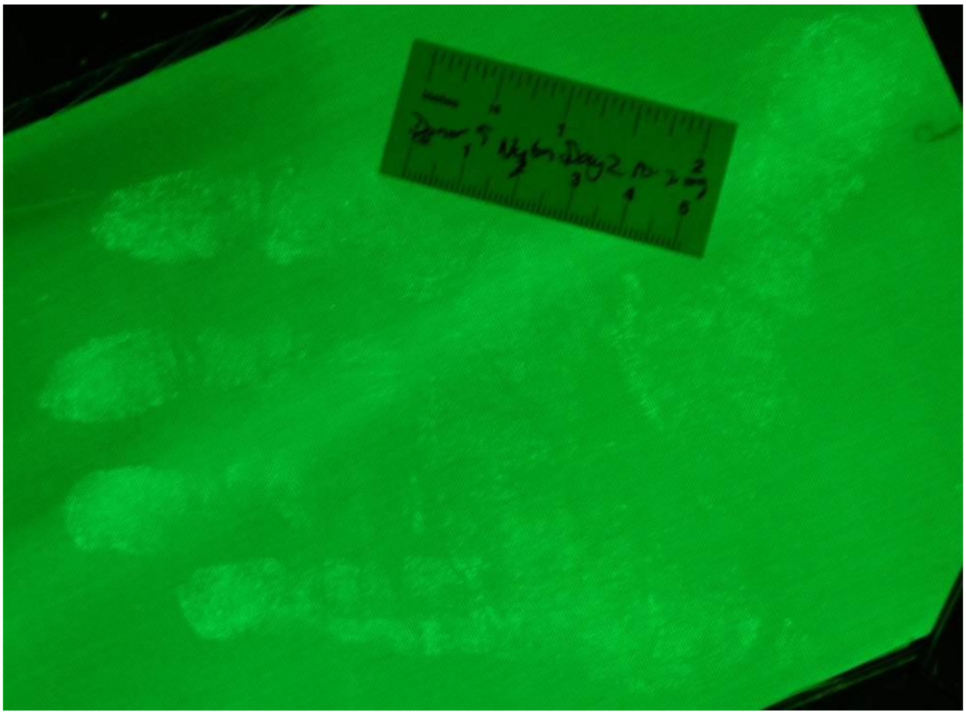


Figure 4.8: Donor nine, day 2, nylon sample, illustrating a hand grab with palm lines. Photographed with a Nikon D40 camera, a yellow (476nm) filter and blue Crime lite (420 - 470nm).

Donor nine [Figure 4.7] had a poor donor rating for all the fabrics and overall fingermark grades of 0, except for nylon, with an overall fingermark grade of 0.8, (calculated from 82 % at grade 0, 15 % at grade 1 and 3 % at grade 2). When considering each fabric separately, cotton had no development in all of the samples; polyester had possible fingertip and thumb marks for days 1, 2 and 7; and polycotton had possible target areas, in the form of possible thumb and fingertip marks, on day 21. Nylon had one fair rating on day 2 (grade 2) [Figure 4.8] as there were palmar flexion creases in the grab mark that could aid in identification. Nylon also had six empty days (1, 4, 5, 7, 14 and 28, grade 1), which gave obvious marks, though these could not be used for identification, as they did not contain any ridge detail, but these areas could be targeted for DNA.

4.10 Donor ten

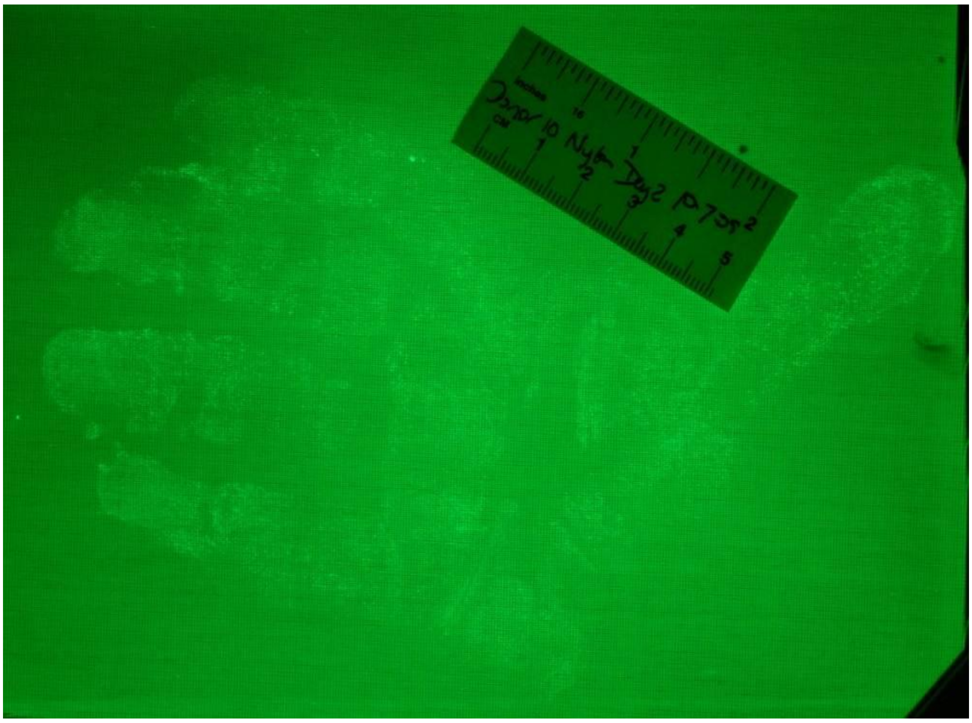


Figure 4.9: Donor ten, day 2, nylon sample, illustrating a hand grab with palm lines. Photographed with a Nikon D40, a yellow (476nm) filter and blue Crime lite (420 - 470nm).

Donor ten had a poor rating for polyester, polycotton and cotton (overall grades of 0) due to lack of development of marks or target areas, though day 3 cotton did have a possible thumb and fingermark so a target area for DNA. The nylon rating was poor also as there was only one no development (day 5, grade 0), along with one fair (day 2, grade 2) and the remaining eight were grade 1, giving an average overall fingermark grade of 1.0. These samples contained some palmar flexion creases [Figure 4.9], which may help produce an identification of the donor, however the very low overall percentages from all the fabrics of 77 % with grade 0, 20 % with grade 1 and 3 % with grade 2 means that identification of the donor is extremely unlikely.

4.11 Donor eleven

Donor eleven had no development for cotton, polyester and polycotton, thus these fabrics had a poor rating and overall fingermark gradings of 0. Nylon had a poor donor rating and an overall fingermark grading of 0.6 due to there being six empty rated days (1, 2, 4, 7, 14 and 21, grade 1), which had grabs and target areas. Though the overall grade percentages from all the fabrics were only 0 (90 %) and 1 (10 %), thus there is little evidence of the fabrics being touched. This could help in confirming or refuting a case scenario as well as giving target areas that could be used to tape for DNA and possibly produce a DNA profile.

4.12 Donor twelve

Donor twelve had a percentage of 85 % at grade 0, 12 % for grade 1 and 3 % for grade 2, thus an overall poor grading. Cotton, polycotton and polyester had overall grade rating 0 due to no development, though there were three possible days on polyester (5, 7 and 14), which could be targeted for DNA. The nylon fabric showed a poor donor rating with an overall grade of 0.7. This was produced from one fair day (day 2, grade 2) with palmar flexion creases; five empty days (3, 6, 7, 14 and 21, grade 1) with some palmar flexion creases and obvious target areas for DNA taping and three no development days (1, 5 and 28, grade 0) with no marks or target areas.

4.13 Donor thirteen

Donor thirteen also had no development (grade 0) for cotton, polyester and polycotton, thus was rated as poor for all three fabrics. Polyester did have one day (day 2) that had a possible target area that could be taped for DNA. Though 80 % of all the swatches were grade 0, nylon had eight samples (20 %) assessed as empty (grade 1), thus giving an overall rating of poor with target areas ranging from extremely faint grabs to full grabs with possible palmar flexion creases that could aid in identification. All of the days with the exception of day 3 produced target areas that could be swabbed for DNA.

4.14 Donor fifteen

Donor fifteen was rated at poor (grade 0) for all the fabrics. Polyester did have one day (day 3) with possible fingertip marks thus an area to target for DNA. Nylon is the only other fabric to have faint grabs and fingertip marks (days 2, 4, 6, 14 and 28), which led to an overall grading of 0.5. One nylon sample (day 28) even had possible palmar flexion creases, which could aid identification, while all the others with the exception of day 3 and 5 have potential target areas. Thus, with overall percentages of 87 % of grade 0 and 13 % of grade 1 identification of the donor would have to come from taping the target areas for DNA, as there is no ridge detail to help with an identification.

4.15 Donor sixteen

Donor sixteen only had two days (7 and 14) that showed possible target areas on polyester, while nylon had four empty days (1, 6, 14 and 21, grade 1) with faint grabs and three days (3, 4 and 7, grade 0) with possible grab and fingertip marks, while all other samples were negative. Thus the overall fingermark grading for nylon was 0.4 while polyester, cotton and polycotton were grade 0, the lack of marks and target areas on all the fabrics resulted in a donor rating of poor. Overall for donor sixteen, the grades were 90 % at 0 and 10 % at grade 1 meaning that there were no identifying details.

4.16 Donor twenty

Donor twenty had a poor rating for all the fabrics, this is due to all the cotton and polyester samples being grade 0, while only one (day 1, grade 0) polycotton sample having possible thumb and fingertip marks. Nylon had three positive samples, one sample (day 6) had a fair rating (grade 2) as the grab mark produced had palmar flexion creases and two samples (day 2 and 5) were rated as empty with faint grabs (grade 1). Overall this donor had 92 % at grade 0, 5 % grade 1 and 3 % grade 2, which would not aid in identification but may point to possible target areas that could be taped for DNA.

4.17 Statistical analysis of CAF fingermark visualisation on cotton, nylon, polyester and polycotton

The Kruskal-Wallis test was performed on data collated on the CAF processed samples, in an attempt to determine which of the fabric types would be most likely to allow the visualisation of ridge detail and the possiblity of an identification. The null hypothesis (H_0) is that there is no difference between fabrics when the visualisation technique is CAF, and the alternative hypotheis (H_A) is that there is a difference.

As can be seen from Table 4.1 all of the fabric sets contained the same number of samples (150) and the same mean rank (258.00) with the exception of nylon (428.00).

Table 4.1: Kruskal-Wallis test using fabric as the grouping variable to compare grades of the four fabrics visualised using CAF. Results show the number of samples in each fabric set, the mean rank of each fabric set, the Kruskal-Wallis value, degrees of freedom and p-value.

Fabric Type	Number	Mean Rank	Kruskal-Wallis Value	Degrees of Freedom	p-value
Cotton	150	258.00	295.813	3	0.000
Nylon	150	428.00			
Polyester	150	258.00			
Polycotton	150	258.00			

The data resulting from the Kruskal-Wallis test and the hypothesis testing carried out resulted in a p-value of <0.001, which means that the H_0 once again should be rejected. Thus, the H_A should be accepted meaning there is a difference between the fabrics and therefore the level of detail that could be visualised, even if it was only a difference between nylon and the other three fabrics.

Nylon, as has been previously been discussed, is the smoothest tightest weave of all four fabrics tested and therefore it may be predicted that this fabric would lead to the most visualisation of detail, confirming the conclusions presented in the chapter 3.

4.18 Overall discussion

Overall, it was only nylon that produced any identifiable grab impressions and palmar flexion creases that could aid in identification. These samples could also aid in corroboration as to whether an assault took place by the position of the mark on the complainant's clothing and the type of mark. For example, if the act were consensual it would not usually involve the complainant being grabbed from behind with the accused's arm coming over the right shoulder grabbing the left side. Therefore, such a mark could indicate someone being dragged backwards or a possible struggle, thus the act being forceful rather than consensual. The positive samples, or those with possible areas of contact, will also give a target area to tape for DNA, which in turn could lead to a DNA profile of the attacker.

It would appear that the fingerprint residues stayed on the smoother tighter weave nylon fabric surface thus allowing the CA fumes to adhere to them. This means the CA polymer forms and absorbs the basic yellow 40 (BY40) making the marks more visible when viewed and photographed under the Quaser. However the loose weave or more porous fabrics allow the residues to be absorbed which means the residues are not available to the CA fumes and therefore no polymer forms even though the fabric had been touched and residues placed on the fabric. This reinforces the opinion that it is the tighter smooth fabrics that are more successful with CAF in visualising fingermark ridge detail and touch areas.

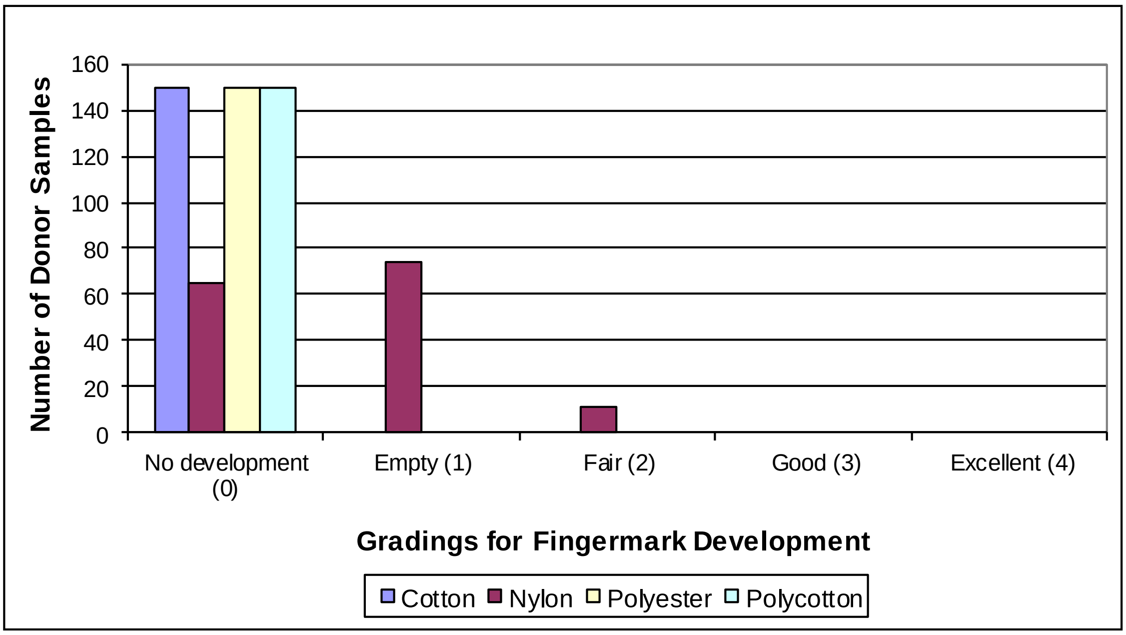


Figure 4.10: Overall number of donor samples with each fingermark grading (0 – 4) of all donors in the study on each fabric type, visualised with CAF.

From the results, it can be seen that all of the donors were graded as poor with none of the fabrics containing any fingermark ridge detail and, in the majority of cases (515 or 86 %), were graded as having no CA development at all [Figure 4.10]. However, of these samples 54 (9 %) had possible CA deposits and thus target areas. Only nylon produced any palm lines, therefore this reinforces the idea that it is the shiny surface of nylon that allows the residues to remain on the surface rather than penetrating the fabric or evaporating, which in turn allows the CA to develop grab and fingertip impressions. However, nylon did not produce many high graded samples with only ten producing ratings of 2 and none of these contained any fingermark ridge detail, but did show some palm lines. Even though the marks themselves cannot be used to identify the assailant they can be targeted for DNA and may lead to an identification.

When considering the results as a whole there does not seem to be a better time after which to develop a sample to visualise marks – the majority of days developed some mark on nylon even if it was just a fingertip impression target area. Of the 150 nylon samples, only 32 developed no impressions and these were spread across all the days from day 1 to day 28. Impressions were found on 118 samples with one day with 100 % of the samples containing impressions (day 14); three days (1, 2 and 7) with fourteen impressions; one day each with thirteen and twelve samples with impressions (days 21 and 6 respectively); one day with ten and nine samples (days 28 and 4) and finally two days (3 and 5) with eight samples. This demonstrates that target areas can be developed on nylon up to twenty-eight days after an incident. Though day one and two have 93 % of samples with target areas, this has dipped, on day three, to 53 %, so it is probably best to try and collect DNA as early as possible. However, after day six the samples with target areas jumped back up to 80 % and higher only dropping to 67 % on day twenty-eight. Of the remaining 450 samples (cotton, polyester and polycotton) only 21 developed target areas. Cotton only had two samples on day 3, polycotton had one sample on day 1 and one on day 21, whereas polyester had the most target areas samples (17) – one on day 1, three on days 2 and 5, seven on day 7, two on day 14 and one on day 28. This lack of impression development further illustrates the point that these duller fabrics do not allow the fingerprint residues to remain on the fabric surface long enough for them to be visualised using CAF. Therefore, these results indicate that shiny manmade fabrics appear to be better at allowing the visualisation of impressions by means of CAF. To confirm this further more research will need to be carried out utilising more manmade and natural fabrics having different surface properties.

5. THE RECOVERY OF FINGERMARKS FROM FABRIC USING VACUUM METAL DEPOSITION (VMD) AND CYANOACRYLATE FUMING (CAF): 7 DAY STUDY ON RAYON, SATIN, NYLON-LYCRA, SILK AND LINEN.

5.1 Aim

To use VMD and CAF in order to determine the level of ridge detail that can be visualised on rayon, satin, nylon-Lycra, silk and linen from fifteen donors after 7 days. The standard grading for donors (good, medium and poor) and samples (0, 1, 2, 3 and 4) were used throughout.

5.2 Results and discussion

Although cotton, polyester, polycotton and nylon are the most common fabrics used in the manufacture of modern clothing others, such as rayon, satin, nylon-Lycra, silk and linen warranted investigation. However, as many of the latter fabrics had been tested previously and used in various student studies it was felt that rather than carrying out the usual full timeline that only day 7 would be studied. This reduction in work would allow new areas of study to be investigated, while validating pervious work as well as giving an overall view as to whether marks could be visualised using VMD and CAF.

As with the previous sections there were 15 donors used on all of the five fabrics (rayon, satin, nylon-Lycra, silk and linen) and these samples were processed after seven days, which resulted in a total of 75 samples. The overall result from rating of the fabrics based on the detail visualised is shown in Figure 5.1. Satin, with two donors of grade 4 (showing full ridge detail); one swatch with a grade 3 (less detail, but enough to aid in identification; seven swatches at grade 2 (limited detail in the fingertips and some palmar flexion creases; four touches (grade 1) and only one with no development. Silk had no grade 4 samples; one grade 3; seven grade 2; six grade 1 and again one grade 0, so there were slightly less samples with identifiable detail compared to satin, though still more detail than the other three fabrics. Rayon, although a tightly woven fabric with a smooth surface (though not as smooth as satin and silk), would be expected to allow the residues to sit on the surface, thus ridge detail could be visualised. Linen, which has a looser more open weave, should show less detail. This is seen from Figure 5.1 with rayon having six samples graded 2, the majority (nine samples) were grade 1 (eight samples) and 0 (one sample). The nylon-

Lycra, however, judging from its characteristics would be expected to show more detail due to the tightness of weave and smoothness of the surface but, in this instance this was not observed. Out of the fifteen samples, there were only six with gradings higher than 0: four at 1 and two at 2 and of these six there were only two that contained any detail, while the other four were only indications of where the fabric had been touched. The reason for the low levels of detail observed on nylon-Lycra may be attributed to highly shiny fabric obscuring some detail or, possibly, the composition of the fabric not allowing the residues to remain on the surface but to be absorbed, therefore not available for VMD visualisation.

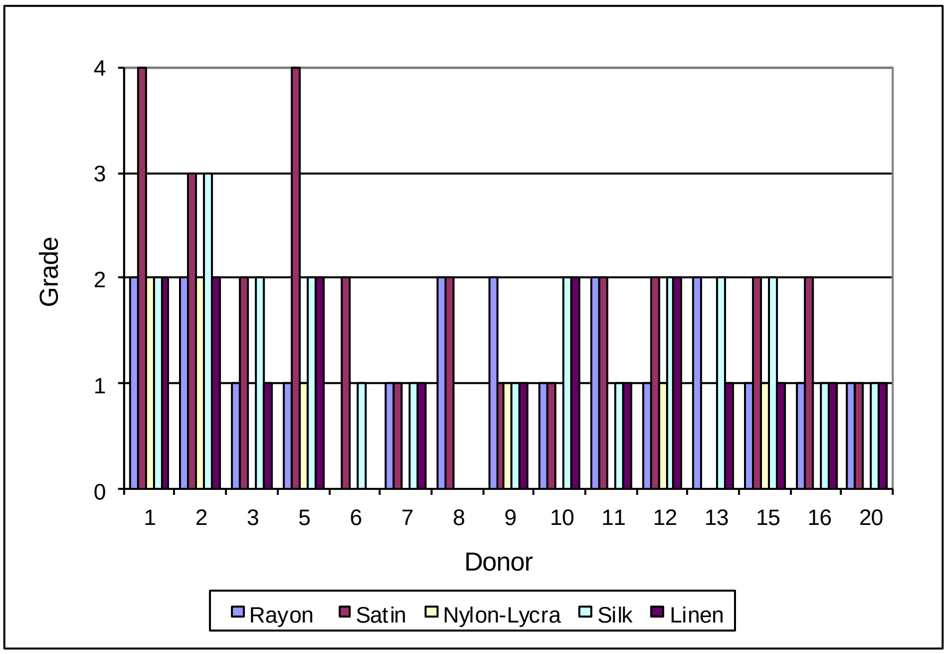


Figure 5.1: Grades of fingermarks visualised with VMD for all donors after 7 days on rayon, satin, nylon-Lycra, silk and linen.

Overall, these fabrics, though only processed for one day (day 7) do follow the trend of the fabrics, cotton, nylon, polycotton and polyester, previously reported in section 3 and 4. Fabrics such as nylon and polyester, with a smoother tighter weave allowed the visualisation of more detail compared to the rougher and/or looser weave fabrics cotton and polycotton.

When considering the donors they too seem to follow the trends found previously with the planted marks of donors one, two and five giving good visualisation with detail compared to donors such as six, seven and ten who generally left marks that led to little or no visualisation. The level of detail observed from each of the visualised samples could be due to the levels of residues produced by the donors, but environmental factors may have contributed. Temperature, either being hotter or colder at the time of collection; what had been eaten (spicy foods) prior to donation of their marks; or exercising.

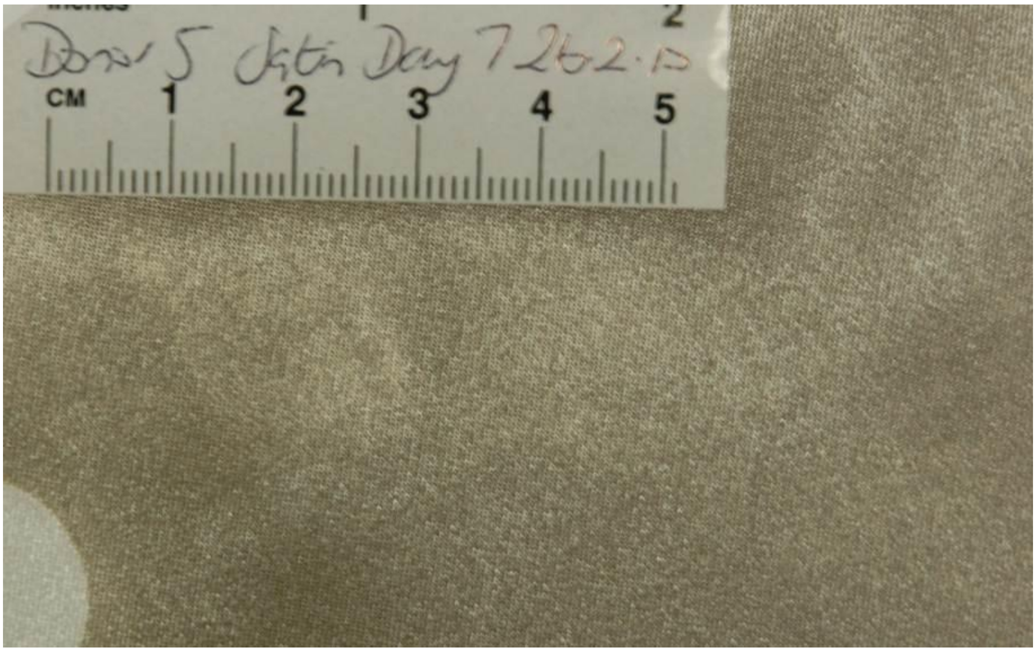


Figure 5.2: Close-up of donor five's thumb mark containing grade 4 detail on a day 7 satin sample. Photograph taken with a Nikon D40 and white light.

Figure 5.3: Example of grab from donor one (day 7 on rayon), containing some palmar flexion creases with empty marks. Photograph taken with a Nikon D40 and white light.

As with all the samples, images were recorded creating a visual record of the detail obtained, however the same level of detail was not always obvious in a recorded image. For example, the mark shown in Figure 5.2 was classed as a grade 4 upon visual examination, however in the photograph this is not observed. This problem may be due to the reflective nature of the surface of the fabric interfering with how the image is recorded digitally, if you compare the grade 2 rayon sample from donor one [Figure 5.3], though there is no ridge detail in the fingertips the palmar flexion creases are more obvious on this matter fabric. This discrepancy between visual examination and recorded images has been observed throughout this research and is an area in which further work needs to be carried out, either using different forms of photography or employing other equipment such as a Nuance multispectral imaging system.

Generally, when looking at the donors individually, for each of the fabrics they do follow a trend – if the donor's marks gave a low grade (0, 1 or 2) for the "better" fabrics (satin or silk) then the other fabrics (rayon, nylon-Lycra and linen) would give even lower values. For example, donor six had a grade of 2 for satin and 1 for silk, while rayon, nylon-Lycra and linen were all graded at 0. A donor with higher grades for satin and silk still had lower grades for the other fabrics; for example, donor two had a grade 3 for satin and silk, with a grade of 2 for all the other fabrics. There are some exceptions to this: donor one has a grade 4 for satin, but a grade 2 for all the other fabrics including silk. Donor ten has a grade 1 for satin, a grade 2 for silk, grade 1 for rayon, and a grade 0 for nylon-Lycra, but a grade 2 for linen, therefore a higher grade for one of the "poorer" fabrics with a lower grade for one of the "better" performing fabrics. This again could be due to several factors, such as environment, diet, exercise, or even how strongly the donor gripped the fabric during their donation.

Very few of the CAF samples [Figure 5.4], gave any indication of the fabric being touched and none of the samples contained detail – only six satin, seven nylon-Lycra, two silk and two linen samples were graded as 1, indicating that the fabric had been touched but all the others were graded as 0. Therefore, this set of day 7 samples followed the trends of the previous studies that VMD was more successful in visualising marks and ridge detail on fabrics than CAF. In some respects this may be due to the basic yellow 40 (BY40) dyeing the fabric also causing considerable background interference as during the staining process hand marks could be seen on some of the rayon samples, however upon viewing with the Crime lites and Quaser these marks could not be seen. Therefore samples treated with CAF may contain more marks and detail than can be seen after the polymer was enhanced with a fluorescent dye. Even though very little was recorded in terms of marks, what was viewed still followed the now expected trend of the smoother tighter weave fabrics (silk and satin) having more positive marks compared to the rougher more open weave linen and rayon.

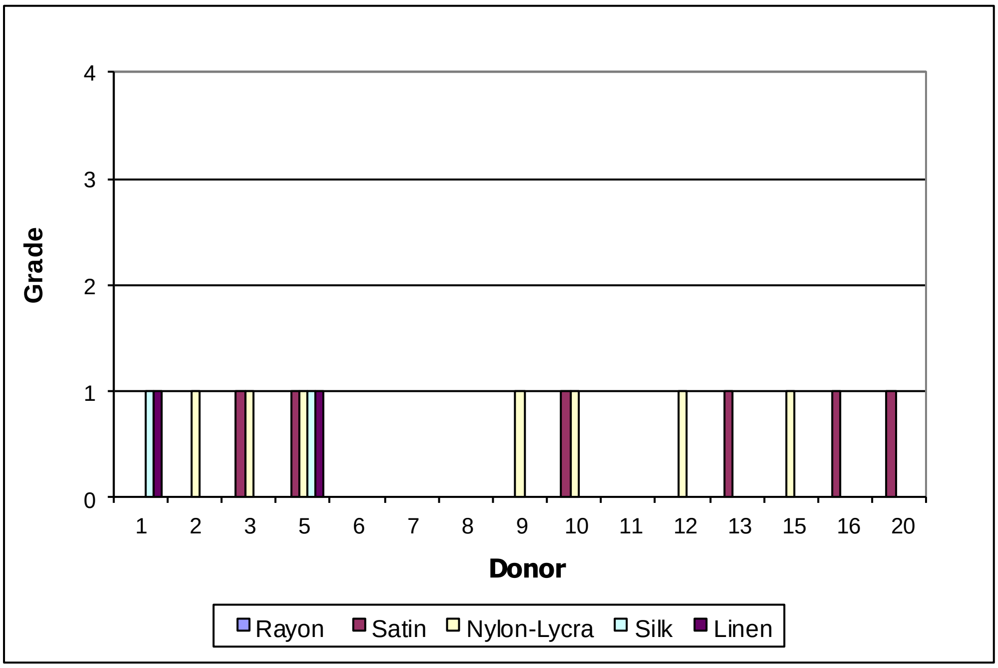


Figure 5.4: Grades of fingermarks visualised with CAF for all donors after 7 days on rayon, satin, nylon-Lycra, silk and linen.

The overall results from rating of the fabrics based on the detail visualised in Figure 5.4, shows that the order, from most detail to least, was nylon-Lycra, satin, joint silk and linen and rayon. This is not unexpected, when considering the surface of the fabric types – both satin and silk have smooth tight weave surfaces, while rayon did not have as smooth a surface, so would be expected. However, the results for linen and nylon-Lycra were unexpected. Linen had a rougher surface, therefore little visualisation would be expected whereas nylon-Lycra fabric was quite smooth and had a tight weave, so it would be expected that more development would be seen. This was not the case as nylon-Lycra, though rated as having the most samples with grades higher than zero overall did not allow for much development of ridge detail or marks possibly. This result may have been due to the deformation of the fabric whilst the fingermark was being deposited.

5.3 Statistical analysis of VMD and CAF fingermark visualisation on rayon, satin, nylon-Lycra and silk.

The Kruskall Wallis test was performed on data collated for the VMD and CAF samples of rayon, satin, nylon-Lycra and silk processed on day 7, to determine the order of level of detail observed on the different fabrics. The null hypothesis (H_0) is that there is no difference between fabrics when the visualisation technique is VMD or CAF, and the alternative hypothesis (H_A) is that there is a difference between the fabrics.

Table 5.1: Kruskal-Wallis test using fabric as the grouping variable to compare grades of the four fabrics visualised using VMD and CAF after 7 days. Results show the number of samples in each fabric set, the mean rank of each fabric set, the Kruskal-Wallis value, degrees of freedom and p-value.

Fabric Type	Number	Mean Rank	Kruskal-Wallis value	Degrees of Freedom	p-value
VMD					
Rayon	15	39.43	18.365	4	0.001
Satin	15	50.20			
Nylon-Lycra	15	20.10			
Silk	15	44.20			
Linen	15	36.07			
CAF					
Rayon	15	29.50	13.209	4	0.010
Satin	15	44.50			
Nylon-Lycra	15	47.00			
Silk	15	34.50			
Linen	15	34.50			

The p-value of 0.001 for VMD and 0.010 for CAF means that the H_0 once again should be rejected for both as there was a difference between the fabrics when the visualisation technique is VMD or CAF. Thus the H_A should again be accepted as there is a difference between the fabrics and therefore the level of detail that could be visualised with both techniques.

As can be seen from Table 5.1 all of the fabric sets contained the same number of samples (15), but had different mean ranks. When comparing the VMD processed samples, satin had the highest mean rank of 50.20, followed by silk (44.20), rayon (39.43), linen (36.07) and, finally, nylon-Lycra (20.10) with the lowest mean rank. With the CAF samples the order was different with nylon-Lycra containing the most detail and a mean rank of 47.00, while satin now had the second highest mean rank (44.50), next was silk and linen with a joint mean rank of 34.50 and rayon was with a mean rank of 29.50. Although this is the same order as discussed in section 5.2 above, thus is statistically confirming that interpretation of the results, there are still some unexpected outcomes. With VMD, nylon-Lycra was the fabric with the lowest mean rank and therefore least level of detail, whereas with CAF the opposite was the case, with nylon-Lycra having the highest mean ranking and therefore the most detail. Nylon-Lycra is a relatively smooth tight weave fabric therefore, it would be expected that this fabric would allow visualisation of fingermarks, though in the case of VMD this did not occur. This may have been due to the surface not allowing the metals to be attached or that when the marks were being deposited the surface was distorted and therefore the residues were not on the surface and available for adherence of the metals. With CAF, nylon-Lycra had most samples with grades higher than zero, though there was little visualisation with this fabric or any of the other fabrics. Therefore, it is hard to determine whether this is the true rank order of these fabrics and more samples would need to be processed to confirm this. However, based on the data collected it would be expected that a smoother fabric such as nylon-Lycra would allow a higher level of visualisation.

A Mann-Whitney U test was also performed to look at each of the fabrics and determine which technique, VMD or CAF, is more suitable and more likely to lead to the visualisation of fingermarks on the fabric's surface and it appears that VMD is the most successful. The H_0 is therefore no difference between the two visualisation techniques of VMD or CAF, and the H_A is that there is a difference between the techniques.

Table 5.2 illustrates this when the mean rank and sum of means of each fabric is considered, four out of the five fabrics - rayon, satin, silk and linen all have values for the VMD technique that are significantly higher than those for the CAF technique. All of the fabrics have mean ranks and sum of ranks for VMD that are approximately twice that for CAF. Therefore, in the case of rayon, satin, silk and linen, VMD should be considered the technique of choice in attempting to visualise fingermarks. Nylon-Lycra is the only fabric where this is not the case with a mean rank of 15.47 and a sum of marks of 232.00 for VMD, while the CAF values were 15.53 and 233.00 respectively, therefore in this instance it could be considered that there is little difference between the two techniques. Thus, either VMD or CAF could be used in an attempt to visualise fingermarks on nylon-Lycra, though the likelihood of visualising any marks would be quite low. This is reinforced by the p-value, as nylon-Lycra is the only fabric being higher than 0.001. All the other fabrics (rayon, satin, silk and linen) have a p-value of <0.001, therefore the (H_A) should be accepted and the conclusion is that there is a difference between VMD and CAF. Whereas nylon-Lycra had a p-value of 0.981, therefore there is little to choose between the two techniques thus the H_0 should be accepted and the H_A rejected.

Table 5.2: Mann-Whitney U test using fabric as the grouping variable to compare grades of the four fabrics visualised using VMD and CAF after 7 days. Results show the number of samples in each fabric set, the mean rank of each fabric set, the sum of the ranks, the Mann-Whitney U value, degrees of freedom and p-value.

Fabric	Technique	Number	Mean Rank	Sum of Ranks	Mann-Whitney U Value	p-value
Nylon-Lycra	VMD	15	15.47	232.00	112.000	0.981
	CAF	15	15.53	233.00		
Rayon	VMD	15	22.50	337.50	7.500	0.000
	CAF	15	8.50	127.50		
Satin	VMD	15	21.50	322.50	22.500	0.000
	CAF	15	9.50	142.50		
Silk	VMD	15	22.03	330.50	14.500	0.000
	CAF	15	8.97	134.50		
Linen	VMD	15	20.08	261.00	25.000	0.000
	CAF	15	9.67	145.00		

In conclusion, the statistical testing showed that VMD is the more suitable technique to use when attempting to visualise fingermarks on the majority of fabrics tested. The fabrics are ranked in the order: satin, silk, rayon, linen and nylon-Lycra for VMD and nylon-Lycra, satin, silk, with linen and rayon being ranked joint last for CAF.

6. Sequential treatment of fabrics

6.1 Aim

To use vacuum metal deposition (VMD) and cyanoacrylate fuming (CAF) sequentially (VMD then CAF or CAF then VMD) to determine the level of fingermark and palm ridge detail that can be visualised on white satin, black satin, nylon, nylon-Lycra and linen from the initial visualised treatment (either VMD or CAF) and the effect of the sequential (either CAF or VMD).

6.2 Results and discussion

As previously stated, VMD is believed to be the more sensitive technique compared to CAF, therefore this study was designed to test this theory as well as determine what effect each technique would have on the other. One set of samples were first processed with VMD the results recorded then processed with CAF to determine the effect this secondary treatment would have on the original results – would they improve the level of marks already on the fabric swatches or would this secondary treatment have a detrimental effect? This was then repeated on samples originally processed with CAF. The marks, if any, were recorded and graded then the swatches were treated with VMD and the results recorded.

Philipson and Bleay (2007) found that the sequential treatment of an item with gold + zinc VMD followed by CAF did lead to an increase in marks visualised as did several police force representatives who attended the VMD Users Group meeting (Downham 2011). However, with the reverse of CAF followed by VMD it was observed that less gold was required for the VMD and that the use of dyes had a negative effect on the final results (Jones 2002). Thus, the same experiment was carried out with a variety of new fabrics using each sequence to determine which developed more positive marks and detail or whether it led to a reduction in the detail that was observed with the single process. VMD followed by CAF was compared to CAF then VMD to determine which was the better sequence and which visualised the most marks.

6.3 Sequential VMD then CAF

6.3.1 VMD only compared to sequential VMD then CAF

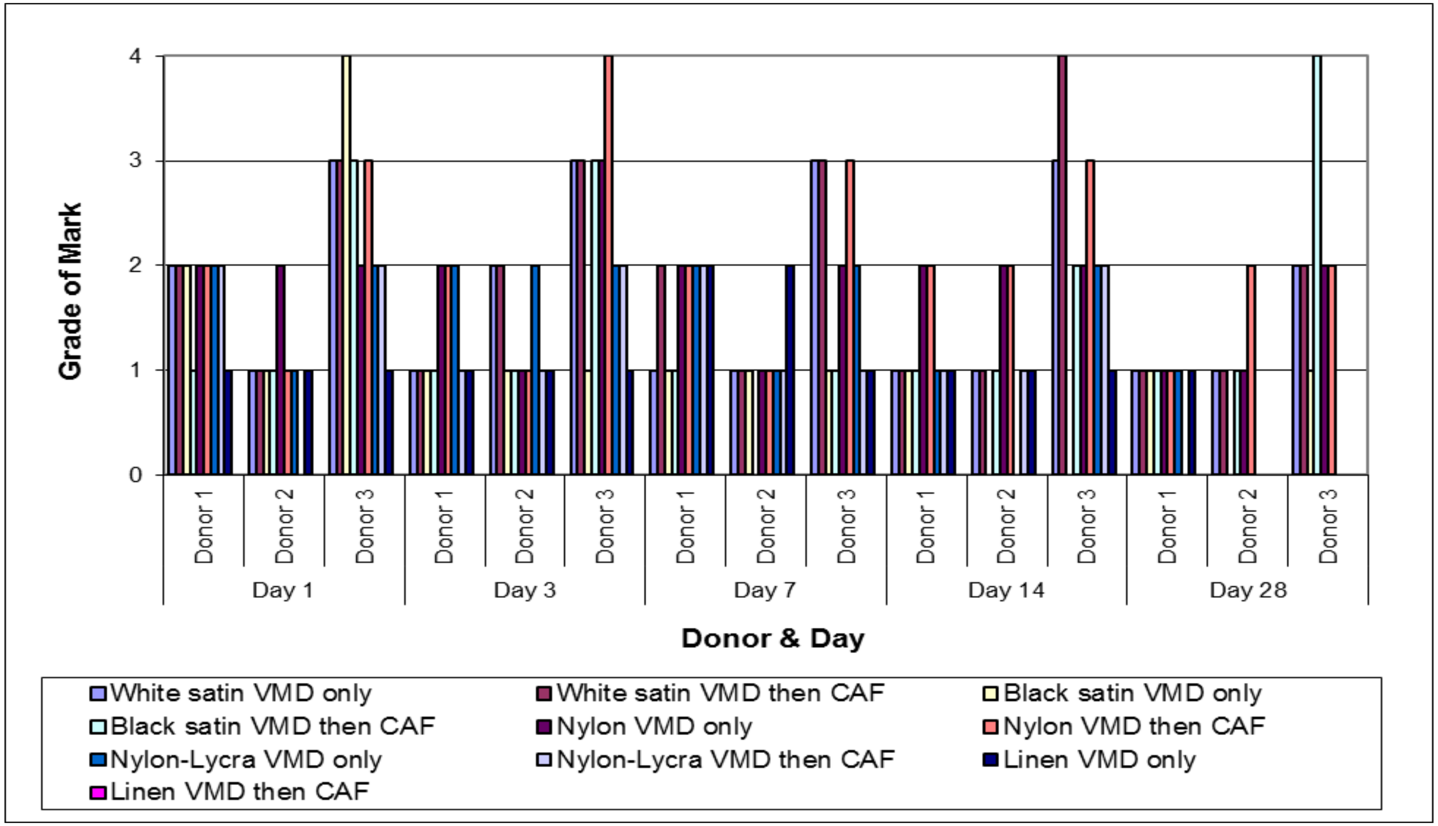


Figure 6.1: Results for a good, medium and poor donor over a time period of 1, 3, 7, 14 and 28 days comparing visualisation using VMD only versus the sequential treatment of VMD followed by CAF. The fabrics processed were white satin, black satin, nylon, nylon-Lycra and linen.

Figure 6.1 shows the singularly VMD treated fabrics side by side with the swatches treated with VMD then CAF. Straight away it is obvious that donor three has higher graded results that the other two donors and that they are the only donor to have any samples graded higher than 2. The other two donors could be ranked second (donor one) and third (donor two), due to the number of grade 2, 1 and 0 samples. These results follow the trends from all the other trials in the study as donor three was generally considered a good donor and consistently produced high graded results, whereas donor one and two, re-numbered from the other trials, were found to have generally been medium (donor one) and poor (donor two), therefore this was again reflected in this trial. To make the results easier to interpret the graph above was split into the separate donors to be discussed separately then compared.

6.3.2 Sequential VMD then CAF Donor one

All the VMD only samples [Figure 6.2] were visible ranging in grades from 1 to 2, there was no ridge detail in the samples, but there were palmar flexion creases on some of the samples, for example white satin day 1. Looking at each fabric separately CAF had little effect on any of the detail observed on any of the different fabrics. White satin stayed the same – grade and level of detail for days 1, 3, 14 and 28, while day 7 resulted in an increase from grade 1 to grade 2. Here CAF enhanced the detail observed by increasing the level of palmar flexion creases viewed. With black satin there was no improvement in detail observed or grade, there appeared to be a slight reduction with the quality of what had been observed with VMD only due to background fluorescence from the basic yellow 40 (BY40). There was also a reduction to the only grade 2 sample with VMD going to a grade 1 after treatment with CAF and BY40. This loss of detail in this sample and the others could be due to the BY40 adhering to the metals as well as the cyanoacrylate (CA) polymer, as the dark colour of the fabric should prevent background fluorescence from ant BY40 absorbed into the fabric itself. With nylon the sequential use of CAF seems to have had no effect on the detail observed with VMD only, therefore no improvement and no reduction, thus no changes in grading. While with nylon-Lycra there was a reduction in grade and quality of two of the samples – days 3 and 28. With day 3 there was a loss of palmar flexion creases, while with day 28 the faint finger impressions completely disappeared. The most obvious change with all the fabrics was with linen, there was little detail after VMD but this completely disappeared after the use of CAF, even the day 7 which was originally a grade 2. Therefore CAF had had a negative effect on the metals on the VMD treated samples; it appears as if the metals "fell off" the swatches.

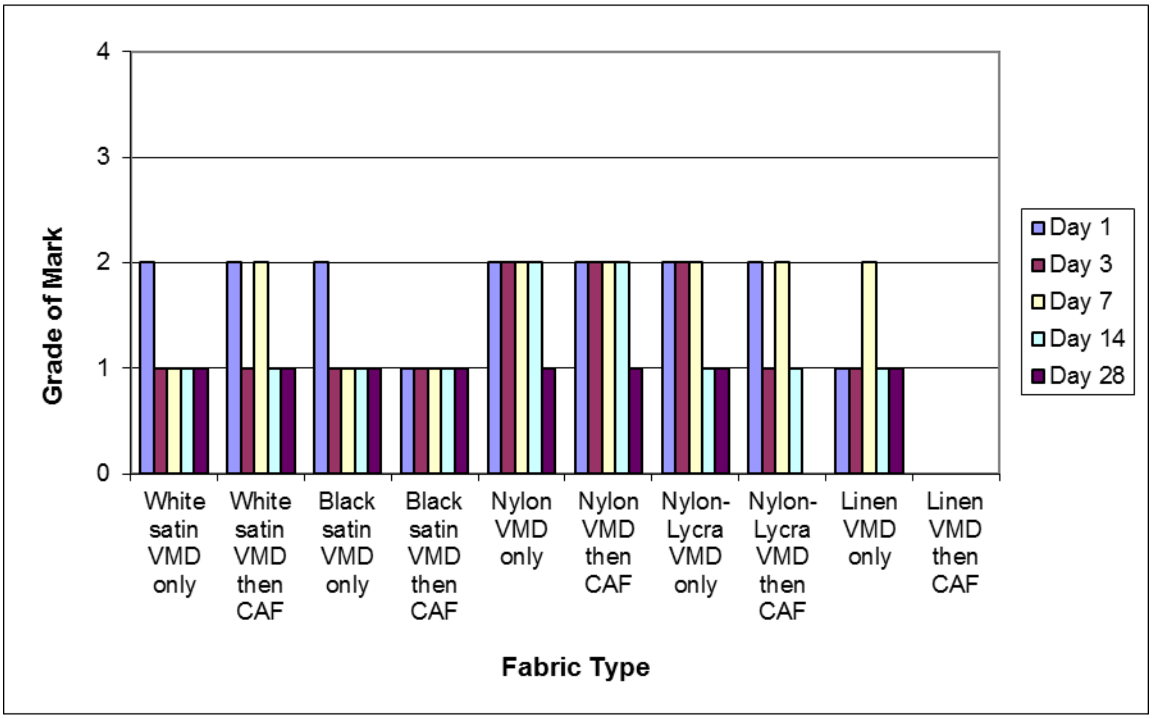


Figure 6.2: Results for donor one over a time period of 1, 3, 7, 14 and 28 days comparing visualisation using VMD only versus the sequential treatment of VMD followed by CAF. The fabrics processed were white satin, black satin, nylon, nylon-Lycra and linen.

This may have been due to the high humidity level in the CAF cabinet causing the metals to oxidise or lose their attraction to the fabric, thus become detached. Therefore overall with this donor CAF did not appear to have a positive or beneficial effect from sequentially treating the fabrics with VMD then CAF as might have been expected from previous research and conversations with practitioners. Only one sample out of the five different fabrics over the whole timeline increased in detail (day 7 white satin), while sixteen samples remained the same (white satin – days 1, 3, 14 and 28; black satin days 3, 7, 14 and 28; nylon days 1, 7 and 14; nylon-Lycra days 1, 7 and 14) and eight samples saw a reduction in grading and quality of detail (black satin day 1; nylon-Lycra days 3 and 28; linen days 1 – 28). Therefore with this donor there does not seem to be an advantage to sequentially treating marks produced by them.

6.3.3 Sequential VMD then CAF Donor two

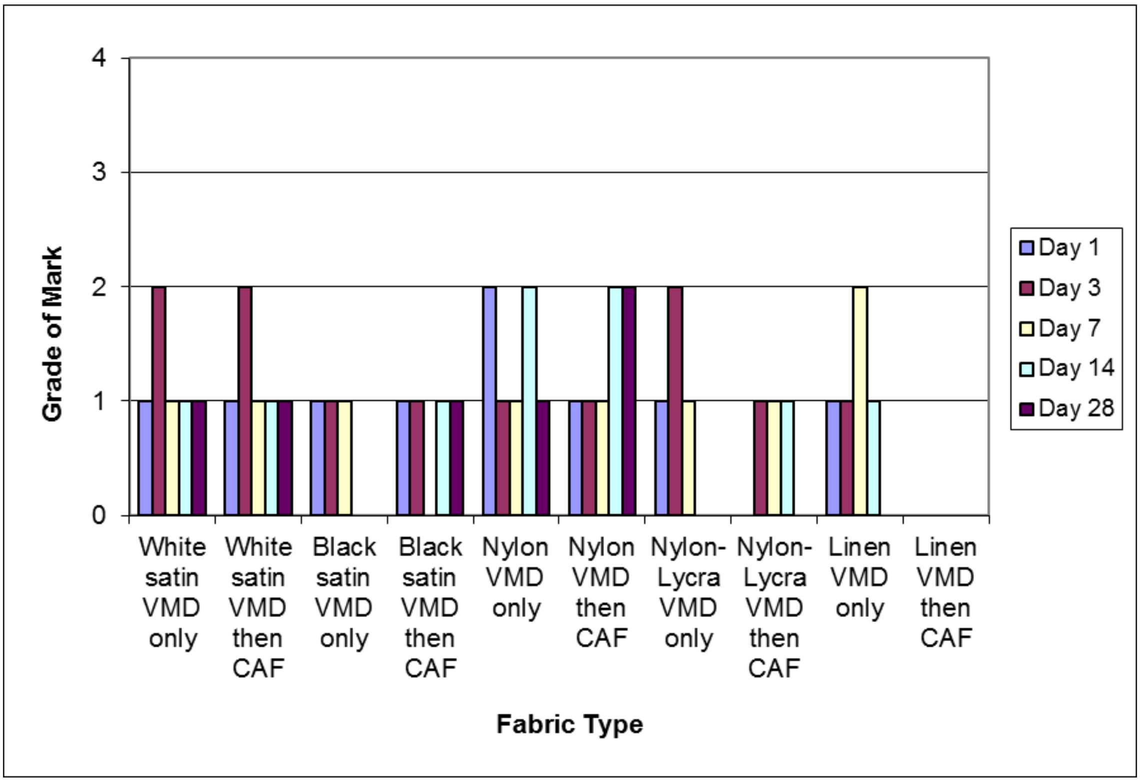


Figure 6.3: Results for donor two over a time period of 1, 3, 7, 14 and 28 days comparing visualisation using VMD only versus the sequential treatment of VMD followed by CAF. The fabrics processed were white satin, black satin, nylon, nylon-Lycra and linen.

The overall initial detail of the samples after VMD [Figure 6.3] was not extremely high, no samples graded over 2, though with this donor several samples were graded as zero (five VMD only samples in total). Though as previously discussed this donor is considered a poor donor, therefore these results are not unexpected. In all there were thirteen samples with grades that remained unchanged, eight that became lower in their grade and only four became higher.

With this donor there does appear to have been some effect from the sequential treatment of the VMD treated samples after CAF and BY40. With white satin the grades of the swatches all remained the same – all the grade one samples remained grade one; however the CAF and addition of BY40 does seem to have made the marks stand out more than with just the VMD. The same occurred with the day 3 sample that was grade 2; it had some extra ridge detail on the index and middle fingertips after CAF and BY40 staining. With black satin two days remained the same gradings (days 1 and 3, both grade 1), though in both cases there was a slight change in the detail observed after CAF – day 1 went from a full to a faint grab, thus a reduction in detail; while day 3 improved in detail from just fingermarks to a faint grab, but both samples were still graded as 1. Day 7 was the only sample that reduced in grading from a 1 to 0 and only possible fingermarks, while days 14 and 28 both went from a grade 0 to a grade 1, nothing to faint fingermarks. Therefore with this donor on these fabrics there was only a small amount of increase in detail, which has not given any extra information that would help with an identification, other than target areas. With nylon most of the samples stayed the same, days 3 and 7 at grade 1 and day 14 at grade 2, though day 3 and 7 became slightly more obvious after the CAF. Day 1 reduced in detail going from a grade 2 to a grade 1 and this appears to be due to a loss of the metal deposits. Day 28 was the only sample to increase in detail going from a grade 1 to grade 2. With nylon-Lycra the younger samples reduced in the observed detail – day 1 reduced from grade 1 to 0 with only possible fingertip impressions, while day 3 dropping from a 2 to 1. Days 7 and 28 remained the same, 1 and 0 respectively, while day 14 was the only sample to improve in detail, going from a negative grade 0 to a grade 1 with possible fingermarks. The final fabric in the set was linen and all samples reduced in quality with the exception of day 28, though this was zero for VMD only and VMD then CAF. The samples that reduced in detail were originally just indications of where the sample was touched, such as a faint grab or fingertip impression, while the day 7 sample had palmar flexion creases, but after CAF and BY40 the was not even an indication of where the sample had been grabbed. Thus with this donor the use of CAF after VMD did not lead to enough extra information or detail to increase the chance of an identification.

6.3.4 Sequential VMD then CAF Donor three

Donor three was the most successful of the donors in this trial as they were the only donor to have samples graded over 2 and the highest number of samples with increased detail/grading, though this donor was generally considered a good donor, so the results were not unexpected. With the other two donors there was not a great deal of improvement or enhancement to the detail observed on the sequentially treated samples. With this donor, there was a little more evidence as to the usefulness of dual treatment. With white satin the majority of the samples, days 1, 3, 7 and 28, all stayed the same grade and all had varying levels of palmar flexion creases and detail. There was one day – day 14, that increased in detail from a grade 3 to a grade 4, so the CAF led to ridge detail being observed on two more fingers. With VMD only there was only ridge detail observed on the ring and little finger, whereas after the CAF all the other fingers contained ridge detail also.

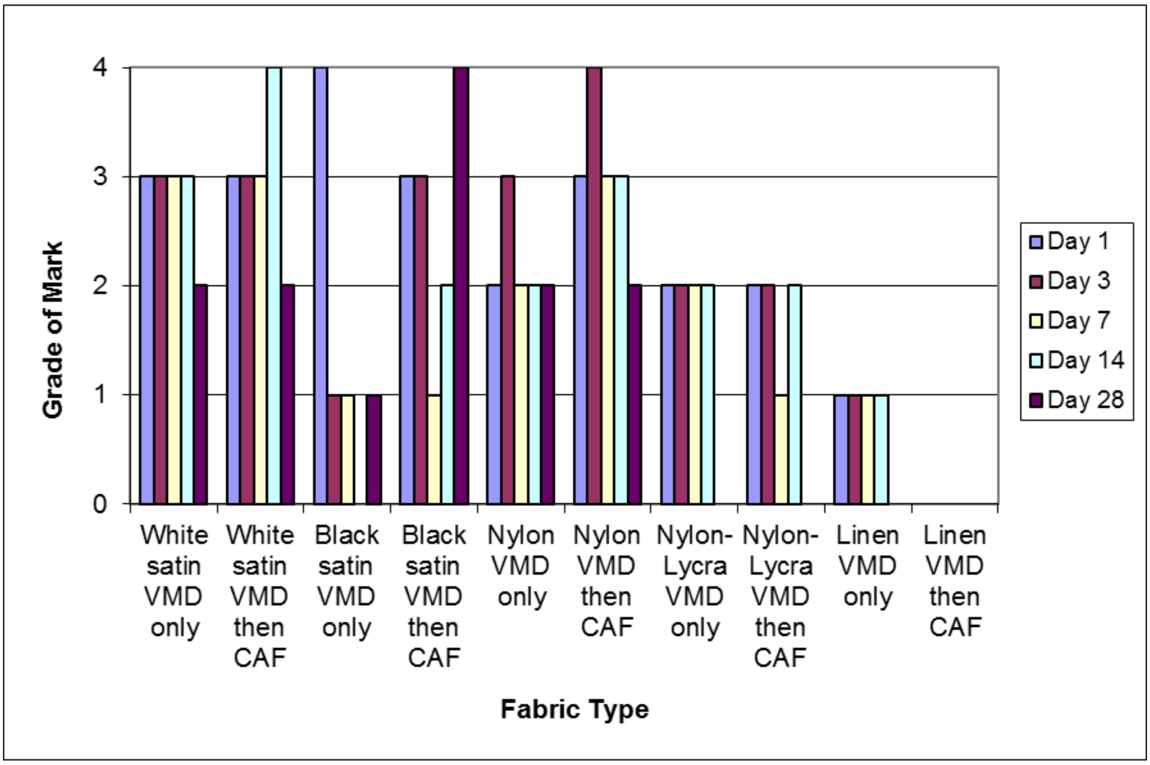


Figure 6.4: Results for donor three over 1, 3, 7, 14 and 28 days comparing visualisation using VMD only versus the sequential treatment of VMD followed by CAF. The fabrics processed were white satin, black satin, nylon, nylon-Lycra and linen.

Black satin had the most improvement of all the fabrics with one of the samples (day 3) rising two grades from a grade 1 to a grade 3 while another (day 14) rising from a grade 0 to a grade 2 and finally day 28 [Figure 6.4] rising from a grade 1 to grade 4 [Figure 6.5]. Thus these samples went from only being negative to a sample with palmar flexion creases (day 14), an empty grab to one with palmar flexion creases and ridge detail in the thumb (day 3) and just a thumb impression to a full grab with ridge detail in the fingers (day 28). Of the other days, one stayed the same – day 7, at only grade 1 and the youngest sample – day 1 lost detail in the fingers going from a grade 4 to a grade 3. Nylon was the other fabric that saw improvement with only one day staying the same grade – day 28 was a grade 2 after VMD and remained a grade 2 even after CAF and BY40. While all the other samples increased in grade and detail - day 1 increased in detail from a grade 2 to 3 starting with palmar flexion creases after VMD then with more detail in the fingertips after CAF; day 7 again went from a grade 2 to a grade 3 with an increase in palmar flexion creases and detail in finger 3; day 14 also increasing from a grade 2 to 3, with palmar flexion creases and empty marks to increased detail and additional detail in thumb; finally day 3 increased from a grade 3 to a grade 4, starting with palmar flexion creases and detail in only finger 1 and 2 to detail in all fingers and thumb. Therefore with nylon and a good donor as in the case of this donor the sequential treatment of CAF after VMD did lead to an enhancement in detail and therefore an increase in the chance of identification. With nylon-Lycra one sample (day 7) reduced in quality from a grade 2 to grade 1 and a loss of detail in the palm, while all the other days 1, 3, 14 and 28 stayed the same with no effect from the additional treatment with CAF.

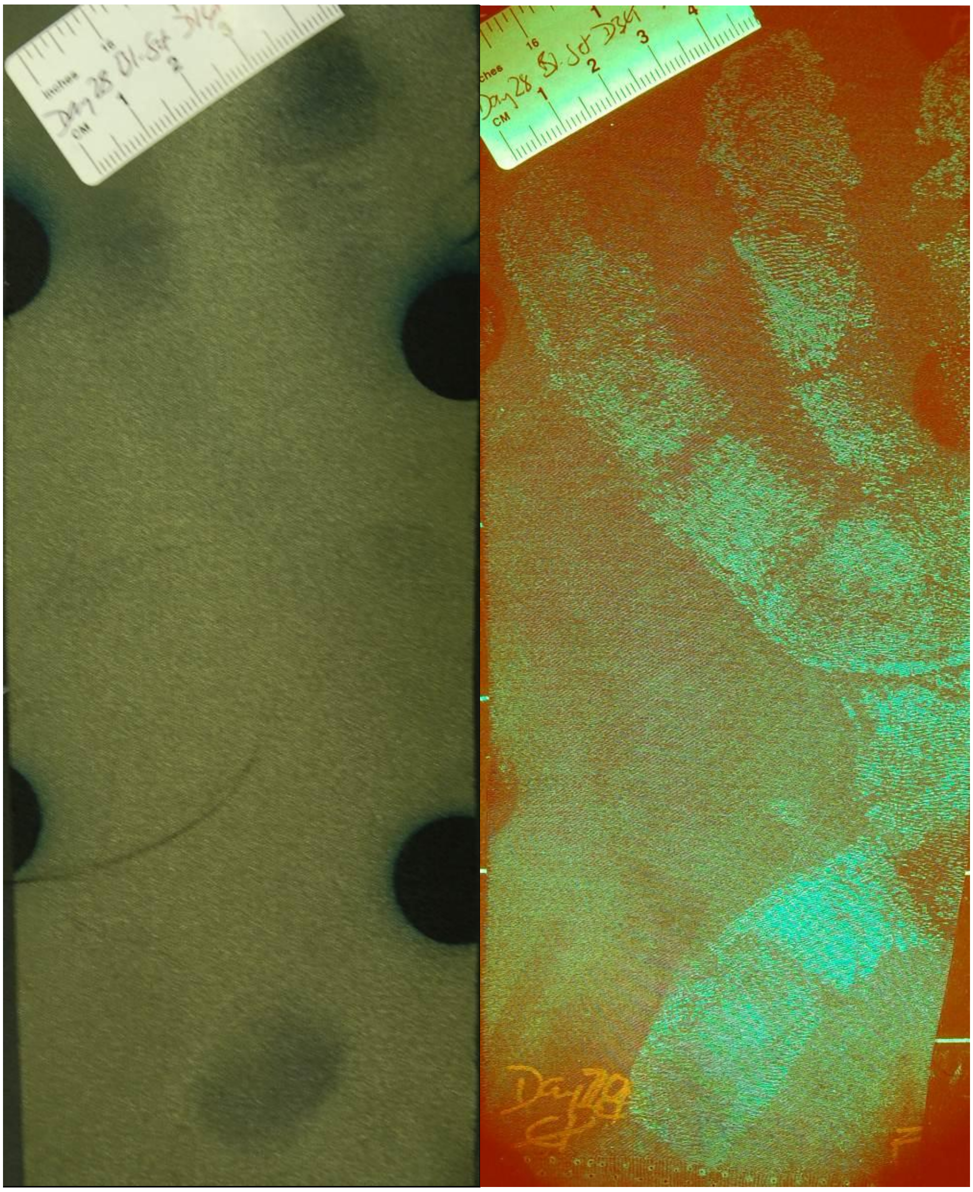


Figure 6.5: Left: Black satin, donor three, day 28, VMD only with only faint indication of where the fabric has been grabbed, though there is no ridge detail observed. Right: the same swatch after sequential treatment with CAF - it is now possible to see ridge detail in all the fingers and on the palm.

Therefore with nylon-Lycra sequential treatment does not seem a worthwhile fabric to sequentially treat to improve detail. The same can be said of linen as this fabric had one sample that remained unchanged (day 28 and grade 0), whereas all the others reduced in the quality of their marks – days 1, 3, 7 and 14 were grade 1 then dropped to grade 0, so faint grabs and indications of touches, such as fingermarks in the case of day 7, to completely negative samples.

To determine whether there was a difference statistically between treating the samples with VMD only and then sequentially with CAF, a Mann-Whitney U test was carried out [Table 6.1]. The null hypothesis (H_0) was therefore that there is no difference between swatches after VMD only and those treated sequentially with CAF, while the alternative hypothesis (H_A) is that there is a difference between the swatches and the treatment to which they have been subjected.

Table 6.1: Mann-Whitney U test of the five fabric samples treated only with VMD and those treated sequentially with VMD then CAF. Details include number of samples, mean rank, sum of ranks, Mann-Whitney U value and p-value.

	Number of samples	Mean Rank	Sum of Ranks	Mann-Whitney U value	p-value
VMD	75	78.87	5915.00	2560.00	0.316
VMD then CAF	75	72.13	5410.00		

From the results it can be seen that due to the p-value being 0.316 that the H_0 should be accepted. Therefore with this p-value as well as the mean ranks and sum of means being relatively close there is not a significant difference between the samples treated only with VMD and then sequentially with CAF.

Table 6.2: Effect on level of detail visualised on fabric samples treated with VMD and then sequentially treated with CAF and BY40, as to whether it remained unchanged, decreased or increased. The grade range of fingermarks for each fabric is also included to demonstrate the level of ridge detail observed on each fabric type.

Fabric type	Level of detail			Grading range
	Unchanged	Decreased	Increased	
White satin	13	0	2	0 – 4
Black satin	7	5	3	0 – 4
Nylon	9	1	5	1 – 4
Nylon-Lycra	9	5	1	0 – 2
Linen	2	13	0	0 - 2

When all the data is collated from all the donors it can be seen [Table 6.2 and Table 6.3] that the majority of samples (53 %) did not change in the detail produced by the original VMD treatment and subsequent treatment with CAF. While 32 % of the samples decreased in grade and detail and only 15 % increased in detail and the majority of these samples, (8 out of the 11 increased swatches) were from the same donor – three. Therefore again the level of detail produced can be seen to be affected by the donor and the level of residues they produce and deposit.

Table 6.3: Chi-squared test results comparing the grade change (unchanged, decreased, increased) observed for the sequential treatment (VMD then CAF) of planted latent marks on five fabrics. Detailing the actual count obtained, the expected count, the percentage of each technique at each grade, as well as the residual value.

Fabric		Effect of CAF on VMD treated samples			
		Unchanged	Decreased	Increased	Total
White satin	Count	13	0	2	15
	Expected count	8.0	4.8	2.2	15.0
	Percentage with grade (%)	86.7	0.0	13.3	100
	Residual	5.0	-4.8	-0.2	
Black satin	Count	7	5	3	15
	Expected count	8.0	4.8	2.2	15.0
	Percentage with grade (%)	46.7	33.3	20.0	100
	Residual	-1.0	0.2	0.8	
Nylon	Count	9	1	5	15
	Expected count	8.0	4.8	2.2	15.0
	Percentage with grade (%)	60.0	6.7	33.3	100
	Residual	1.0	-3.8	2.8	
Nylon-Lycra	Count	9	5	1	15
	Expected count	8.0	4.8	2.2	15.0
	Percentage with grade (%)	60.0	33.3	6.7	100
	Residual	1.0	0.2	-1.2	
Linen	Count	2	13	0	15
	Expected count	8.0	4.8	2.2	15.0
	Percentage with grade (%)	13.3	86.7	0.0	100
	Residual	-6.0	8.2	-2.2	
Total	Count	40	24	11	75
	Expected count	40.0	24.0	11.0	75.0
	Percentage with grade (%)	53.3	32.0	14.7	100

With the chi-square test also carried out reinforcing these findings discussed above. The null hypothesis (H_0) in this case is that there was no increase or decrease in the detail observed on the VMD treated fabrics after being sequentially treated with

CAF. Therefore, the alternative hypothesis (H_A) is that there is a difference in detail between the VMD only treated fabrics and those that were treated sequentially with CAF. This led to the χ^2 (8) = 36.561 p<0.001, therefore the H_0 should be rejected due to such a low p-value and the H_A accepted, which in turn illustrates that there is a significant difference in the ridge detail observed on the fabric swatches after being sequential treated with CAF.

With the information for the tables above the fabrics can be ranked as to their level of positive detail from gradings to level after sequential treatment and the order is nylon; white satin; black satin; nylon and linen (highest to lowest). When the grading range within each fabric is considered the order does not really change nylon is still first, followed by the two satins in joint second place, then nylon-Lycra and linen being joint last. Nylon was second equal highest for samples staying the same grade after sequential treatment and equal to nylon-Lycra, while it had the least number of samples that became worse, only one of its day 1 sample; it also had the highest number of samples that improved in grade and detail observed after the sequential treatment. Thus it could be presumed that nylon items would be more likely to stay the same or increasing in detail than decreasing if they were treated with CAF after they had been treated firstly with VMD. However when the information in Table 6.3 is taken into account, the expected counts were different from the actual counts in that the number that the expected number was 4.8, but the actual number was 1. In the case of the increased samples the expected value was 2.2, whereas the actual number was 5. White satin had no samples that reduced in detail, the majority – 13 in total stayed the same and two samples increased in their level of detail. Again, the expected counts (4.8) illustrate that statistically it would have been expected that more samples would have decreased in detail, whereas no samples decreased in value. Therefore, white satin items are more likely to stay the same but there may be an increase in detail on items handled by a medium to good donor. With black satin nearly half the samples (7) stayed the same with no addition detail visualised, while only 3 samples increased in detail and the remaining 5 reduced in detail. However, all the values were quite close to the expected values as shown in Table 6.3. Thus with black satin items are just as likely to decrease as they are to increase in detail therefore a decision would have to be made as to whether a sequential treatment would be carried out as it may be detrimental. However, as ridge detail would most likely be recorded between treatments it may be useful to attempt CAF after VMD. With Nylon-Lycra over half of the samples (9) stayed the same grade, which is close to the expected value of 8 and did not display much more if any extra detail, 5 samples, the same as with black satin, reduced in detail, whereas only one sample increased in grade and therefore detail. Thus nylon-Lycra items are more likely to reduce in detail than increase, which in turn means using CAF after VMD on linen would most likely not be of any benefit. Finally with linen the metal deposited on the fabric during the VMD process appeared to "fall off" the swatches during the CAF process. Therefore any detail originally seen was lost, which in turn means there would be little point in sequentially processing linen with VMD then CAF as no extra detail would be produced and target areas for DNA would be lost along with information about the sequence of events that may have taken place. This unusual effect of the loss of metals is illustrated by the results, where the expected decrease value was only 4.8 and the unchanged value was 8, which is quite different from the actual values of 13 and 2 respectively.

Overall, the order of fabric follows the general trend of the smooth tighter weave the more detail, as does the order of improvement from sequential treatment. It was the smooth manmade fabrics that had more improved detail and less samples with reduced detail, whereas the natural fabric used in the study (linen), had no improvement, it only had two samples that stayed the same and all the others, 87 % in total, reduced in detail. The reduction in detail on some of the samples may be in part to do with the humidity in the CAF cabinet loosening the metals attachments to the fabrics' surfaces or may be to do with the use of BY40 after the CAF. It has been suggested by Jones (2002) that the use of dyes have a detrimental effect on the detail already produced with items that were processed first with CAF then VMD, therefore future work should be carried out into this area and possibly trying CAF without the use of BY40 after. This would allow it to be determined as to whether there was an effect from the use of BY40. It should be noted, however. that due to the use of donors planting natural marks rather than the use of an artificial residue stamp there cannot be a guarantee that there definitely was a mark planted each time. Therefore, there are limitations to this study and if repeated the use of a stamp could be considered. However, in this study, the researcher was attempting to keep the deposition method close to what might occur during a real-life scenario and this is why a stamp and artificial residues were not used.

6.4 Sequential CAF then VMD

6.4.1 CAF only compared to sequential CAF then VMD

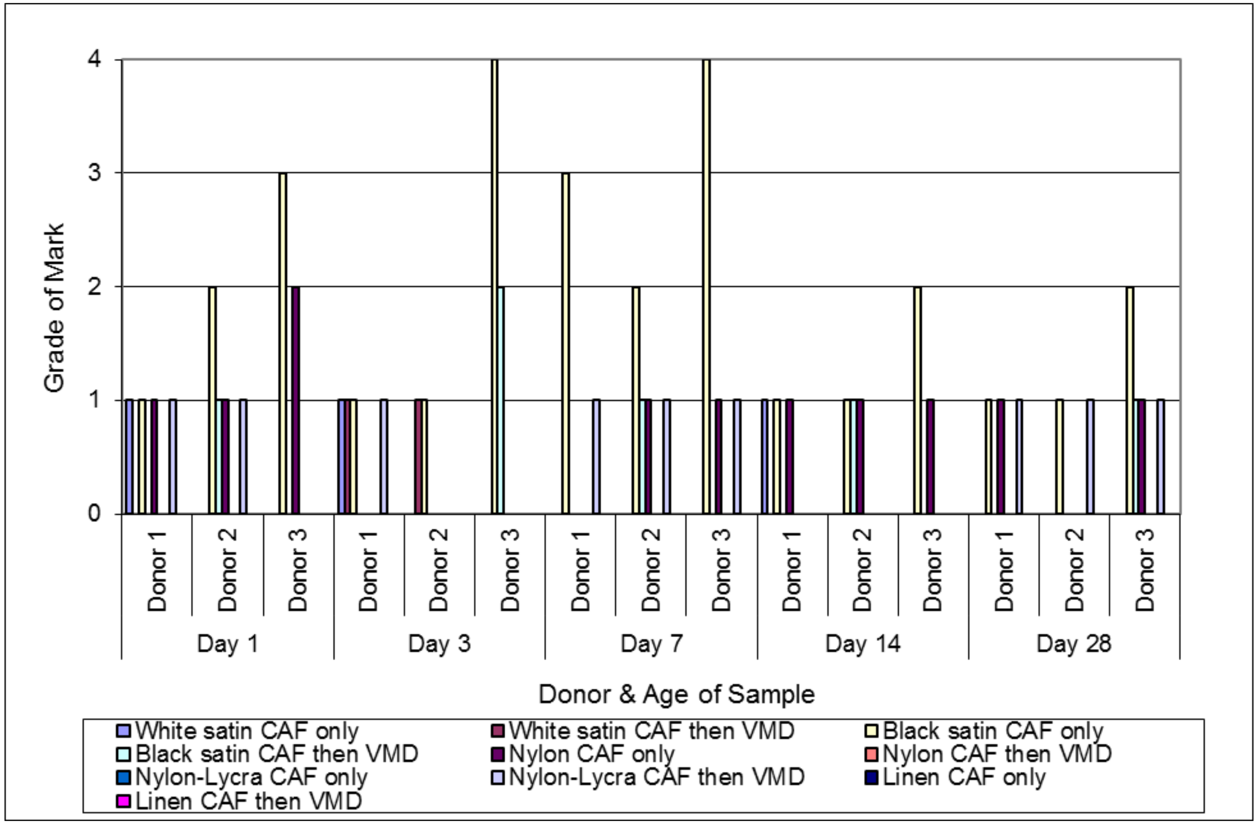


Figure 6.6: Results for a good, medium and poor donor over a time period of 1, 3, 7, 14 and 28 days comparing visualisation using CAF only, versus the sequential treatment of CAF followed by VMD. The fabrics processed were white satin, black satin, nylon, nylon-Lycra and linen.

CAF followed by VMD is the preferred sequence by many practitioners, however from the information that can be seen in Figure 6.6, CAF is not very successful with the fabrics used in this trial. There are very few positive samples when compared to the results of VMD followed by CAF and, of the donors, again it is donor three who has the most positive and highest graded samples, followed by donor one and then two, though this time the difference between donor one and two is not as pronounced.

6.4.2 Sequential CAF then VMD - Donor one

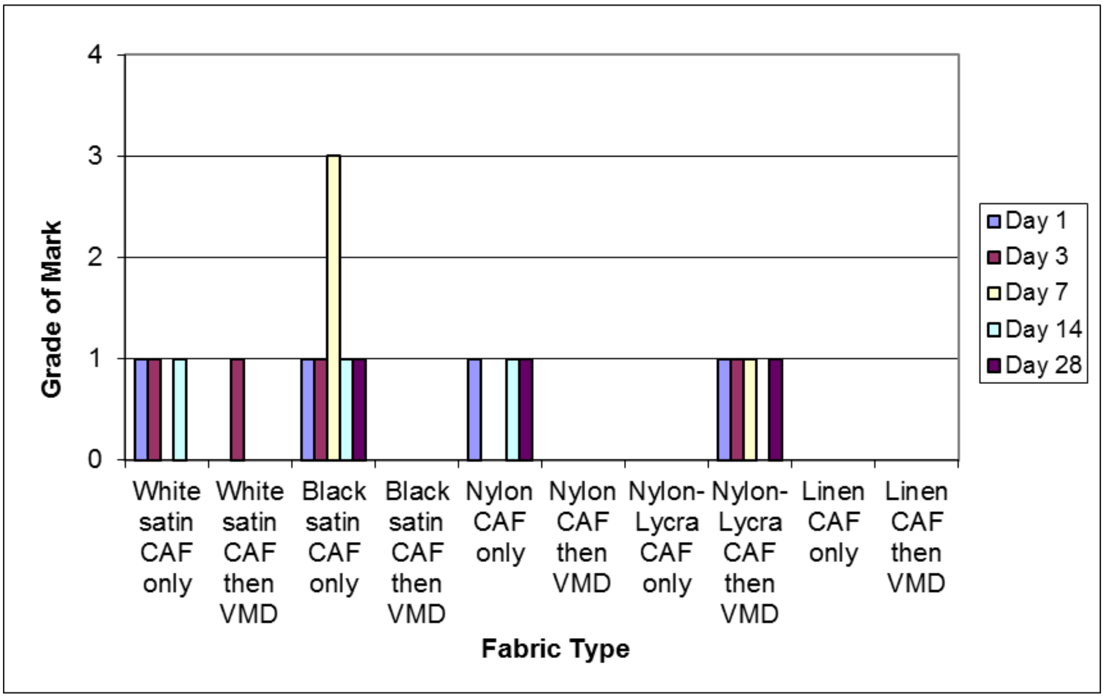


Figure 6.7: Results for donor one over a time period of 1, 3, 7, 14 and 28 days comparing visualisation using CAF only, versus the sequential treatment of CAF followed by VMD. The fabrics processed were white satin, black satin, nylon, nylon-Lycra and linen.

White satin [Figure 6.7] is the only sample that did not lose all the detail of all the samples first visualised – day 3 was originally graded 1 and remained at this grade, though they were only finger and thumb marks. Two other days remained the same grade – day 7 and 28, though these were graded as zero, so there was nothing to start with. Two days decreased in their level of detail - day 1, which was originally a faint fingermark with the CAF treatment reducing to only a possible fingermark and a grade 0; while day 14 started at a grade 1 faint grab dropping to a grade 0 and only a possible target area. With black satin, this is obviously not the sequence to use as all of the detail visualised with CAF was lost once VMD was carried out over the top, even with the grade 3 day 7 sample. Nylon only had three positive samples after CAF, all graded 1. Day 1 dropped from a grab to only a possible thumb and fingertip impressions; day 14 dropped from a grab to a possible fingertip impression and day 28 from a grab to nothing, just a negative sample. With days 3 and 7 the grades started at 0 and remained at 0. Linen did not produce any positive samples after CAF and this was not improved by the use of VMD – all the days remained at a grade of 0. Nylon-Lycra was the only fabric where there was any improvement on the originally treated swatches - days 1, 3, 7 and 28 all started at grade 0 rising to grade 1 after the sequential VMD. Day 1 rose from nothing, a negative sample, to an extremely faint grab; day 3 rose to a grab, no detail and parts of hand missing; day 7 to a possible thumb and finger; day 14 to a possible thumb mark and finally day 28 became a faint grab. Overall this donor had eleven samples that remained unchanged in their grade; ten samples lost detail and became lower in grade, while four samples, all linen displayed more detail after the sequential treatment.

6.4.3 Sequential CAF then VMD - Donor two

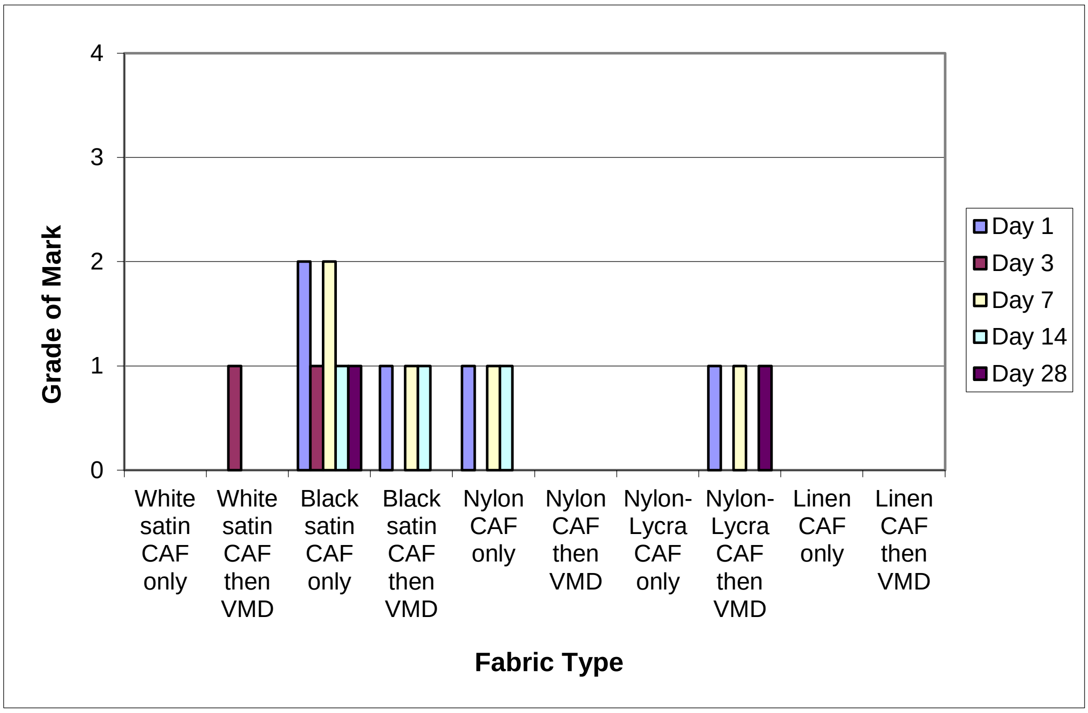


Figure 6.8: Results for donor two over a time period of 1, 3, 7, 14 and 28 days comparing visualisation using CAF only, versus the sequential treatment of CAF followed by VMD. The fabrics processed were white satin, black satin, nylon, nylon-Lycra and linen.

With this donor [Figure 6.8] there was also very little in the way of positive samples and of those samples even less remained positive after the sequential treatment of VMD. White satin was zero for all days, with the exception of day 3, this sample changed from a zero grade and negative to a grade 1 and possible target area. Black satin again lost the majority of the detail originally visualised with CAF - day 14 remained the same (grade 1), a faint grab to faint fingertip and thumb impression. Day 1 lost detail dropping from a grade 2 to 1 (a grab to a faint grab); day 7 also dropped from a grade 2 to 1, from a grab with partial ridge detail in thumb to fingertip impression only; days 3 and 28 dropped from a grade 1 to a grade 0 – a grab and faint grab to negative blank samples. Nylon had two days (3 and 28) which started as grade 0 and remained at this grade, while the other days (1, 7 and 14) all lost detail - day 1 was only a fingertip and thumb impression, then became a negative; while day 7 started as a fingertip and dropped to only possible target area; with day 14 starting as a faint grab to another negative sample. Linen again like donor one did not produce any detail after CAF only or CAF then VMD. Again nylon-Lycra produced positive samples after sequential VMD from samples that had no detail from the originally CAF treated samples. There was no detail with days 3 and 14 – graded 0 for both CAF and CAF then VMD, but days 1, 7 and 28 all improved from a grade 0 to grade 1 – negative to possible finger impressions. Overall, with this donor the majority of samples remained unchanged – fourteen in total, though the majority were and remained grade 0 (nine and 64 % or 12 % overall), while seven samples dropped in detail and grading (9 %) and only four increased in detail (5 %). Thus this reinforces that the only fabric out of those used in this section that could benefit from this sequential method is nylon-Lycra, all other fabrics performed worse after sequential CAF then VMD, with only the day 3 white satin improving its grading, though this was not a great change in grade or detail observed.

6.4.4 <u>Sequential CAF then VMD Donor three</u>

White satin [Figure 6.9] was graded as 0 for all days, though days 7 and 28 had possible fingertip impressions after the sequential VMD. Black satin, as with the other two donors, again lost detail with all of the days - day 1 dropped from a grade 3 to grade 0, from a full grab to only a possible grab. Day 3 dropped from a grade 4 to grade 2, from a grab with palmar flexion creases and ridge detail to a faint grab and only possible palmar flexion creases. Day 7 went from an excellent grade 4 to a negative grade 0 from a grab, with ridge detail and palmar flexion creases to nothing and day 14 dropped from a grade 2 to 0, full grab with some palmar flexion creases to nothing. Finally day 28 dropped from a grade 2 to a grade 1 - a full grab with some palmar flexion creases to only a faint grab and no detail.

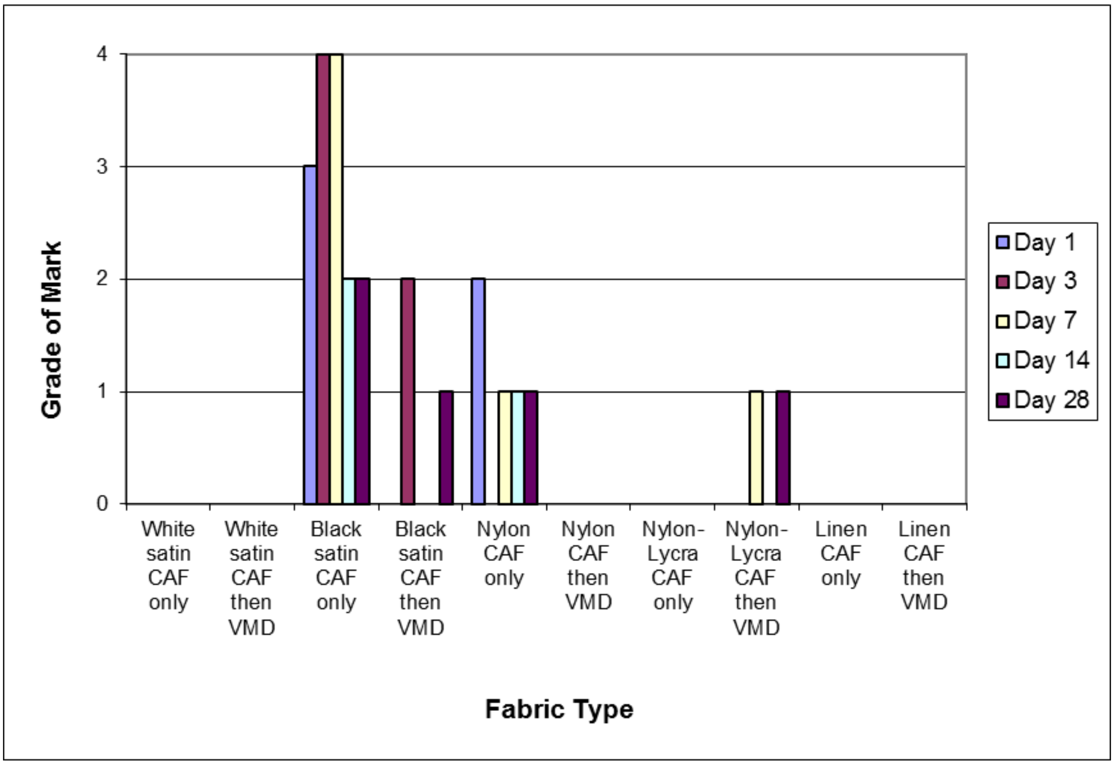


Figure 6.9: Results for donor three over a time period of 1, 3, 7, 14 and 28 days comparing visualisation using CAF only, versus the sequential treatment of CAF followed by VMD. The fabrics processed were white satin, black satin, nylon, nylon-Lycra and linen.

Nylon the same as the other donors had some positive samples with just CAF (days 7, 14 and 28 – grade 1 and day 1 – grade 2), but all this detail was lost after the sequential treatment with VMD. The samples dropped from - day 1 a grade 2 with a full grab and palmar flexion creases to a negative sample with no indication of even a touch; day 7 dropped from a faint finger impressions to a negative sample; day 14 again a grab to nothing and day 28 a faint grab to only a possible fingertip impression. The final day – day 3, did not have any detail from the start, was a grade 0 after CAF and remained a grade 0 after CAF then VMD. Once more, linen displayed no detail for any days after either treatment. While nylon-Lycra again was the most positive fabric in terms of positive samples after the sequential treatment – though with this donor three of the samples remained zero grades – day 1 had very little metal deposits at all, while both days 3 and 14 were negative after only CAF, but had possible finger impressions after the sequential VMD. Days 7 and 28 both improved and had positive marks after the VMD - day 7 had a partial grab, while day 28 had a finger impression and partial grab after the VMD. Thus overall with this donor fourteen samples that did not change and these were all grade 0; nine samples dropped in grade and only two samples increased in detail and grade.

There were several samples that were graded as zero for the original process of CAF and they remained at this grade even after subsequent processing with VMD, therefore there may be some concern that a mark was not deposited in the deposition stage. This may of course be the case as the marks left were natural and no artificial residues were utilised, however the deposition method of natural marks was chosen to replicate the actions that would occur during an assault. Further work could be carried out with an artificial residue to validate these results. However, from previous CAF studies the fabrics with these zero grades did not show many marks, therefore grades higher than zero would not necessarily have been expected.

To determine whether there was a difference statistically between treating the samples with CAF only and then sequentially with VMD, a Mann-Whitney U test was carried out [Table 6.4]. The null hypothesis (H_0) was therefore that there is no difference between samples after VMD only and those treated sequentially with VMD, while the alternative hypotheis (H_A) is that there is a difference between the swatches after the treatments.

Table 6.4: Mann-Whitney U test of five fabric samples treated only with CAF and those treated sequentially with CAF then VMD. Details include number of samples, mean rank, sum of ranks, Mann-Whitney U value and p-value.

	Number of samples	Mean Rank	Sum of Ranks	Mann-Whitney U value	p-value
CAF	75	82.30	6172.50	2302.500	0.016
CAF then VMD	75	68.70	5152.00		

From the results it can be determined, due to the p-value of 0.016, that the H_A should be accepted. Therefore, the p-value as well as the mean ranks and sum of means show there is a significant difference between the samples treated only with CAF and then sequentially with VMD.

After collating all the data from all the donor's samples first visualised with CAF and basic yellow 40 followed by VMD it can be seen [Table 6.5 and 6.6] that the majority of samples (52 %) did not change in the detail or grade first produced by the original CAF treatment. The remaining samples either decreased in grade and detail (35 %) or increased in grade and detail (13 %). These figures are extremely similar to those obtained by the VMD then CAF sequential sequence; however the starting grades for these figures were much lower. Overall there were only forty four positive samples - thirty four grade 1, six grade 2, two grade 3 and two grade 4 samples.

Table 6.5: Effect on level of detail visualised on five fabric samples treated with CAF and BY40 and then sequentially treated with VMD. The grade range of fingermarks for each fabric is also included to demonstrate the level of ridge detail observed on each fabric type.

Fabric type	Level of detail			Grading range
	Unchanged	Decreased	Increased	
White satin	12	2	1	0 – 1
Black satin	1	14	0	0 – 4
Nylon	5	10	0	0 – 2
Nylon-Lycra	6	0	9	0 – 1
Linen	15	0	0	0

A chi-square test was carried out resulting in χ^2 (8) = 78.949 $p<0.001$, which indicates that the H_A that is accepted, as there is a difference between the way the samples have been treated.

With the information from Table 6.5 and 6.6 the fabrics can be ranked as to their level of positive detail from gradings to level after sequential treatment and the order is nylon-Lycra; white satin; nylon; black satin; linen (highest to lowest). When the grading range within each fabric is considered the order is quite different – black satin is first with the highest grading of 4, followed by nylon, then the white satin and nylon-Lycra tied with their highest grade only being 1, then finally linen, with all samples before and after sequential treatment grading 0. Nylon-Lycra was the third highest for samples staying the same grade after sequential treatment (six), third only to linen and white satin, it did not have any decreased samples that became worse after sequential VMD treatment, and finally nylon-Lycra had the highest number of samples that increased in detail, nine in total. Thus, it could be presumed that nylon-Lycra items would be more likely to increase in detail if they had been treated with CAF then VMD, whereas the expected count (5.2) showed that more samples were expected to decrease in detail. White satin had two samples that reduced in detail, the majority – twelve in total stayed the same and one sample increased in its level of detail. Therefore white satin items are more likely to remain unchanged than increase or decrease in detail, even though statistically fewer samples (7.8 compared to 12) were expected to stay unchanged, while 5.2 were expected to decrease and 2.0 to increase, compared to the actual results of 2 and 1.

Table 6.6: Chi-squared test results comparing the grades and grade change (unchanged, decreased, increased) observed for the sequential treatment (CAF then VMD) of planted latent marks on five fabrics.

Fabric		Effect of CAF on VMD treated samples			
		Unchanged	Decreased	Increased	Total
White satin	Count	12	2	1	15
	Expected count	7.8	5.2	2.0	15.0
	Percentage with grade (%)	80.00	13.3	6.7	100
	Residual	4.2	-3.2	-1.0	
Black satin	Count	1	14	0	15
	Expected count	7.8	5.2	2.0	15.0
	Percentage with grade (%)	6.7	93.3	0.0	100
	Residual	-6.8	8.8	-2.0	
Nylon	Count	5	10	0	15
	Expected count	7.8	5.2	2.0	15.0
	Percentage with grade (%)	33.3	66.7	0.0	100
	Residual	-2.8	4.8	-2.0	
Nylon-Lycra	Count	6	0	9	15
	Expected count	7.8	5.2	2.0	15.0
	Percentage with grade (%)	40.0	0.0	60.0	100
	Residual	-1.8	-5.2	7.0	
Linen	Count	15	0	0	15
	Expected count	7.8	5.2	2.0	15.0
	Percentage with grade (%)	100	0.0	0.0	100
	Residual	7.2	-5.2	-2.0	
Total	Count	39	26	10	75
	Expected count	39.	26.0	10.0	75.0
	Percentage with grade (%)	52.00	34.7	13.3	100

With nylon, only five samples remained unchanged while the remaining ten samples all reduced in detail – there was very little detail to start with, but after the sequential VMD treatment the majority of detail disappeared. Therefore, nylon items sequentially treated with CAF then VMD will most likely lose any detail that was originally visualised by CAF, thus this is not a suitable treatment sequence for nylon. The expected counts in Table 6.6 showed that nylon was expected to have less decrease in detail (5.2 compared to the actual 10), while more samples were expected to remain unchanged (7.8, compared to 5) and some samples were expected to increase in detail (2 compared to 0). Black satin one sample stayed the same with no addition detail visualised, all the remaining fourteen samples reduced in detail, which is quite different to the expected counts of 7.8 unchanged, 5.2 decreased and 2 increased. Thus with black satin items are most likely to decrease in detail, thus this sequence would again not be advised as a way of increasing detail. Finally, with linen no detail was visualised with CAF or after VMD was used to sequentially treat the samples, which again is quite different to the expected statistical results which indicate that there should be 7.8 unchanged, 5.2 decreased and 2 increased. Thus, it seems that with linen, the use of CAF or CAF and then sequential VMD treatment, will not lead to visualisation of any detail, so it appears that VMD alone is the best method to treat this fabric.

Overall, the order of fabric again seems to be following the general trend of the smooth tighter weave the more detail as does the order of improvement from sequential treatment. Though as with the previous sections in this study, there is less detail in the CAF treated samples than there were with the original VMD treated samples. There were only 44 samples in total that were positive (59 %), while the remaining 41 % were negative, which seems to reinforce that CAF is the less effective treatment on fabrics and that the BY40 dye may be negatively impacting on the visualisation.

6.5 Conclusion

The use of VMD then CAF did seem to increase the detail visualised on the samples on some fabrics or at least make the detail more obvious and easier to see, such as the donor three black satin swatches. However, some of the samples did not change or the sequential treatment was detrimental to the original detail visualised. On some fabrics the CAF process appeared to remove the metal deposits from the fabric – linen is a prime example, the limited detail and metals deposits seems to completely disappear after the CAF and no new or additional detail was observed after the BY40 staining and viewing under the Quaser or Crime lites. With the CAF then VMD, this seemed to reduce the amount of detail or marks previously visualised with CAF only on the majority of fabrics and samples. This may be due to the VMD metals attaching to the fabric and the CAF deposited afterward adhering to these metals as well as the fingerprint residues thus disguising any marks previously noted.

Therefore this current research seems to support the use of VMD over CAF, however if they were to be used sequentially this trial suggests to use CAF after VMD. More work obviously needs to be done in this area with more donors and fabrics to determine the full extent of sequential treatment and its impact on visualised detail. However, overall satin seems to benefit from sequential VMD then CAF, as does nylon, though nylon-Lycra and linen do not. With CAF then VMD the only fabric that seems to benefit from this sequential treatment is nylon-Lycra.

7. COMPARISON OF THE RECOVERY OF FINGERMARKS FROM FABRIC USING VACUUM METAL DEPOSITION (VMD) AND CYANOACRYLATE FUMING (CAF)

Note: this work is a comparative study of the two techniques of VMD and CAF carried out by myself (Researcher one and four) and, where indicated, Forensic Science Honour's project students (named researchers two, three, five, six and seven) under my guidance.

7.1 Aims

To investigate the effectiveness of metal deposition (VMD) and cyanoacrylate fuming (CAF) in visualising planted fingermarks and palm marks on various pre-cut fabric swatches of cotton, polycotton, polyester, nylon and satin.

7.2 Background

Fifteen donors planted their marks using either a natural or loaded method of deposition utilising either a grab and/or push technique. These donors ranged in age, sex and ability to leave latent fingermarks.

Once the impressions were planted the fabric swatches were aged for varying lengths of time – 1, 2, 3, 4, 5, 6, 7, 14, 21 and 28 days, and then processed with either VMD or CAF. Once visualised the samples were graded as to whether target areas were visible as well as the amount of ridge detail and palm marks visualised, using the scale 0, 1, 2, 3 or 4 – 0 being no development and 4 being excellent.

Both VMD and CAF were investigated to determine their effectiveness in the visualisation of fingermark and hand mark impressions on fabric swatches, as a model for the usefulness of these techniques in the visualisation of fingermarks on clothing collected from cases of sexual and/or physical attacks. The visualisation of these marks could help in the identification of those involved in assault cases through ridge detail and palmar flexion creases as well as visualising areas that could be targeted for DNA collection then profiling. These marks can also help in corroborating a sequence of events. For example, a consensual encounter is less likely to involve marks that indicate the complainant was grabbed from behind or a person whose family are convinced they did not commit suicide by jumping in front of a train, would have marks on their back indicating a push.

To optimise and standardise the results obtained, all the researchers followed exactly the same procedures (see section 7.3) for the techniques used (VMD and CAF) as well as using the same pieces of equipment (Edwards 24" metal deposition machine, Mason Vactron Ltd, UK and MVC 3000 or MVC 5000, foster+freeman). Identical procedural checks were performed before using the equipment and all the researchers utilised the same donors and timelines, as detailed in sections 7.5 and 7.7. There was also an attempt to use fabric from the same bolt, however this was not always possible due to only 5-10 metres of each fabric being purchased at a time and that these studies took place over several years. However, in order to try to reduce that amount of variation between each purchase and increase the chances of the same fabric from the same bolt being purchased, the same fabric source was used – either Whaleys (Bradford) Ltd. (online) or Kings Fabric (Dundee). Finally, though each researcher used a slightly different fingerprint-grading scheme a combination was utilised to produce the one detailed in section 7.8. It should also be noted that the main researcher initially checked the grades assigned by the other researchers and it was confirmed that these researchers were grading in the same manner as the main researcher.

7.3 Processes used in the study

Table 7.1: VMD procedural details used by researchers 1, 2 and 3, including metals used, pump down and evaporation pressures, and sample number processed per VMD run. The same Edwards 24" Metal Deposition Unit, manufactured by Mason Vactron Ltd UK was used by each researcher.

VMD Researcher			
	1	2	3
Wire type	Gold 2-3mm	Silver (99 %) 3 x 0.5mm diameter and 5mm in length	Gold 2-3mm
Aluminium foil	1 g		1 g
Pump down pressure	4 x 10^{-1} mbar	3 x 10^{-1} mbar	4 x 10^{-1} mbar
Metal evaporation – high pressure	3 X 10^{-4} mbar	4 X 10^{-4} mbar	3 X 10^{-4} mbar
Sample number	1	1	1

Table 7.2: CAF procedural details used by researcher 4, 5, 6 and 7, including glue quantity, humidity cycle, glue application and purge cycles, as well as dye used, length of dyeing process and light source used for enhancement.

	CAF Researcher			
	4	5	6	7
Cyanoacrylate (MVC 3000/5000)	2 or 4 g	2 or 4 g	2 or 4 g	2 or 4 g
Humidity	79 %	80 %	79 %	80 %
Temperature	120.7 °C	100 °C	120.7 °C	120 °C
Humidity cycle	15 minutes	20 minutes	15 minutes	15 minutes
Glueing cycle	15 minutes	20 minutes	15 minutes	20, 40 and 60 minutes
Purge cycle (MVC 3000/5000)	20/40 minutes	20/40 minutes	20/40 minutes	20/40 minutes
Dye	BY40 dye (2 g) dissolved in ethanol (1L)	BY40 dye (2 g) dissolved in ethanol (1L)	BY40 dye (2 g) dissolved in ethanol (1L)	BY40 dye (2 g) dissolved in ethanol (1L)
Dye submersion time	1 minute	1 minute	1 minute	1 minute
Light source	laser light (350-469 nm)	a forensic light (450-485 nm)	laser light (350-469 nm)	laser light (352-469 nm)

7.4 Fabrics used in studies

Table 7.3: Fabrics used by researchers 1-7 for VMD and CAF trials. Fabrics were selected as being representative of those commonly used in the manufacture of modern clothing and all had a minimum count of 3 threads per mm.

	Researcher						
Fabric type	1	2	3	4	5	6	7
Nylon	White		White	White	White	White	White
Cotton	White	Dark blue	White	White		White	
Polyester	White	Black	White	White	Navy	White	
Polycotton	White	Black		White		White	White
Satin		Black			Black	White	Green
Silk			White		Navy		Multi-coloured
Lycra			White				
Linen			White		Lilac		
Polyester/cotton (65/35 %)			White				
Polyvinyl chloride (PVC)			White		Brown		
Nylon-Lycra					Black		
Wool					Black and cream		
Nylon/polyester					Pink		

7.5 Donors used in studies

All the researchers used donors from the main study's donor pool - fifteen donors were common between the four of studies (researcher 1, 2, 4 and 6), while researcher 7 only used ten donors, researcher 5 used two and researcher 3 only used one donor. The donors used in the studies were a mixture of men and women, with the exception of researchers 3 and 5 who both only used males. All these donors ranged in their ability to deposit latent fingermarks on fabric and were therefore classed as good, medium and poor.

7.6 Deposition methods used in studies

To simulate an assault the donors used a grab or grab and push form of donations, as well as either natural marks, where no extra residues were added to the donor's hands or loaded marks, which involved the donor wiping their fingers and palms over their forehead, nose and behind their ears to add extra sebaceous and sweat secretions.

Table 7.4: Details of methods used by each researcher during study including type of deposition, sample placement, deposition method and the length of time taken in depositing the marks.

Researcher	Deposition type	Sample placement for deposition	Deposition method	Time of deposition
1	Natural	Fabric laid over lab coat covered arm of researcher	Grab	10 seconds
2	Loaded	Fabric wrapped round researcher's lab coat covered arm secured with elastic bands	Grab	5 seconds
		Fabric placed on bench and donor pressing onto it as hard as possible	Push	
3	Loaded	Fabric laid over researcher's lab coat covered	Grab	5 seconds
		Fabric laid on table	Push	
4	Natural	Fabric laid over lab coat covered arm of researcher	Grab	10 seconds
5	Loaded	Fabric laid on table	Push	5 seconds
6	Loaded	Fabric laid on table	Push	5 seconds
7	Loaded	Fabric laid on table and sequential marks left in 4 sections	Push	5 seconds per section

7.7 Timelines used in studies

Generally, the same timeline of 1 to 28 days was used, though some researchers did not use the full range, as shown below.

VMD - Days 1, 2, 3, 4, 5, 6, 7, 14, 21 and 28 (researcher 2, no results for days 5, 6, 14 or 28)

CAF – Days 1, 2, 4, 5, 6, 7, 14, 21 and 28 (researcher 7, no results for days 2, 4, 6, 14 or 28)

7.8 Fingermark grading used in studies

Each researcher had their own set of grading criteria that has been combined to produce the set below.

Excellent (4) – good ridge detail on all 5 fingertips and palm with visible pores, ridge edge detail and ridge flow.

Good (3) – ridge characteristics (Galton details) visible on at least 3 fingers or approximately 1/3 to 2/3 partial detail on all fingermarks.

Fair (2) – Full pattern and ridge flow on 1 or 2 fingers or approximately 1/3 partial detail on all the fingers and/or palmar flexion creases visible, but not enough detail for identification.

Empty (1) – the location where the donor had touched the fabric could be seen, but no ridge detail observed on fingertips or palm.

No development (0) – negative, no visible or recognisable marks on fabric.

7.9 VMD donor grading

When comparing all the fabrics and donors tested [Figure 7.1] there did appear to be a trend, even if the donors are not consistently at the same rating for different fabrics. For example, donor one consistently developed the highest gradings, such as good on nylon; medium on polycotton and silk; medium to good on polyester; poor to medium on cotton and poor on satin, Lycra, linen and PVC. This, in turn, reinforces the view stated above that this donor leaves good marks, even though they were now consistently rated as a good donor. Donors five and fourteen could also be considered good donors with a mix of good (donor fourteen on nylon), medium to good (donor five on nylon), medium (donor five on polycotton and polyester and donor fourteen on polyester), medium to poor (donor fourteen on polycotton) and poor (both five and fourteen on satin and cotton). The other donors could be ranked as good to medium (donors two, four, six, eleven and fifteen), medium (donors nine and ten), medium to poor (donors twelve and thirteen) and poor (donors three, seven and eight) – these were poor donors for all the fabrics tested. Donor seven was expected to be a poor donor due to their performance in other trials and the results in the current trials reinforced this. This poor donor rating may be due in part to donor seven having dry hands, thus lack of fingerprint residues. Donors three and eight had not previously been tested experimentally but discussions about the dryness of their skin and contact with chemicals pointed to them being poor donors. Differences in environmental factors can also lead to an effect on the amount of secretions and therefore the fingerprint residues deposited as well as how much pressure was used to deposit the marks on the fabrics.

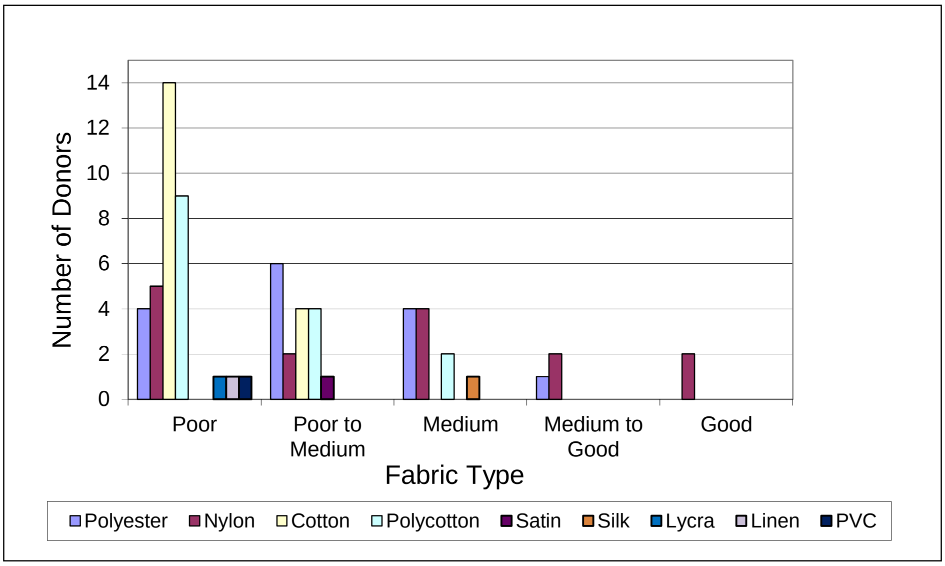


Figure 7.1: Combined donor grading in the study on each fabric type visualised with VMD. The grading ranged from poor to good depending on level of detail displayed in each sample processed, poor having little or no detail up to good with ridge detail and/or palmar flexion creases.

7.9.1 Cotton

Generally, as illustrated in the table below [Table 7.5], cotton did not allow the visualisation of fingermark ridge detail – only donors one and two had any gradings higher than 1, while all the other donors either left latent marks that did not visualise after VMD or only showed areas of contact (grade 1). The grades that were higher than 1 tended to be on the younger samples – days 1 and 3, though donor one did have a grade 2 sample on day 7. This could indicate, especially with the days 1 and 3 samples, that the fingerprint residues are quite quickly absorbed into the cotton therefore not available for VMD visualisation. The higher than expected grade on day

7 could have been a spurious result due to the donor being exposed to different environmental factors such as heat, exercising prior to donation or different food consumption, all of which could have led to higher than normal fingerprint residues being produced and therefore deposited on that sample. Due to the low gradings for the majority of samples all the donors, except donor one, were graded as poor. Donor one had a grading of poor to medium due to three of the samples containing some level of ridge detail and/or palmar flexion creases.

Table 7.5: VMD donor rating and range of donor fingermark gradings for each day on cotton illustrating the effect of age on the ridge detail visualised.

Donor	Day										Donor rating
	1	2	3	4	5	6	7	14	21	28	
1	1-3	1	1-2	0-1	1	0-1	0-2	0-1	0-1	0-1	Poor - Medium
2	1-2	0-1	0-1	0-1	1	0	1	1	1	1	Poor
3	0-1	0-1	0-1	0	0-1	0-1	0	0-1	0-1	0	Poor
4	0-1	1	0-1	1	0	0	0-1	0	0-1	0-1	Poor
5	0	0	0-1	0-1	0-1	0-1	0	0-1	0	0	Poor
6	0-1	0	0	0-1	0-1	0	0-1	0	0	0-1	Poor
7	0-1	0-1	0-1	0-1	0	0-1	0-1	0	0-1	0	Poor
8	0-1	0-1	0	0	0	0	0	1	0-1	0-1	Poor
9	0-1	0-1	0-1	0	0-1	0	0	0-1	0-1	0	Poor
10	0	0-1	0-1	0	0	0	1	0	0	0-1	Poor
11	0-1	0-1	0-1	0	0-1	0-1	0-1	0-1	0	0	Poor
12	0	0	0	0	0-1	0	0-1	0	0	0	Poor
13	0-1	0-1	0	0	0-1	0-1	0-1	0-1	0-1	0	Poor
14	1	0-1	0-1	0-1	1	1	1	0-1	0	0	Poor
15	0-1	0-1	0-1	0-1	0	0	0	0-1	0	0	Poor

7.9.2 <u>Polycotton</u>

Polycotton had the full range of fingermark gradings between all the donors, from no development (0) to full ridge detail (4) which equates to a mixture of poor to medium donors. Again, it is donor one who had the best detail developed across the full timeline – every day contained samples that contained identifiable ridge detail (grade 2 – 4) and led to donor one being classed as a medium donor. Donor five was also classed as medium, as they too had 6 out of 10 samples with identifiable ridge detail. However, with this donor, the majority of days had samples with no development and two days (6 and 28) graded 0. There were four other donors (two, four, eleven and fourteen) who left some level of identifiable ridge detail over the timeline. These donors ranged in detail from 0 to 4 though there did not seem to be any consistency as to when the higher fingermark grades were visualised, which again illustrates the variability of deposits left by different individuals. Donor two was the most consistent of the four donors in terms of depositing similar grades across the timeline. Therefore, it could be concluded that this donor produces constant levels of residues and these residues remain on the surface of the fabric allowing them to be visualised by the VMD process.

Table 7.6: Polycotton VMD donor rating and range of donor fingermark gradings for each day illustrating the effect of age on the ridge detail visualised on the samples .

Donor	Day										Donor rating
	1	2	3	4	5	6	7	14	21	28	
1	1-4	1-3	1-4	1-4	1-3	1-3	1-4	1-4	0-3	1-4	Medium
2	1-3	1-2	1	1	1	1-3	1-2	1-2	1-2	1-2	Poor - Medium
3	0	0-2	0-2	0	0-1	0-1	0	0-1	1	0	Poor
4	1-2	1	0-1	0-1	0-2	0	0-1	0	0	1	Poor - Medium
5	0-2	0-3	0-1	0-2	0-1	0	0-2	1-3	0-3	0	Medium
6	0-1	0-1	0-1	0-1	0-2	0	0-1	0-1	0-1	0-1	Poor
7	0-1	0-1	0-1	0	0-1	0-1	0-1	0-1	0	0-1	Poor
8	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	1	Poor
9	0-2	1	0-1	0-1	1	0-1	0-1	0-1	0-1	0-1	Poor
10	1	1	0-1	0-1	0-1	0-1	1	0	0	0	Poor
11	0-1	1	1-2	0-3	0-1	0-3	0-1	0-1	0-1	0-3	Poor - Medium
12	0-1	0-1	0	0	0-1	0-1	0-1	0-1	0-1	0	Poor
13	0-3	0-1	0-1	0-1	0-1	0-1	0-2	0-1	0-1	0	Poor
14	1	1-2	1-2	1	1-3	1	1-4	0	0	1	Poor - Medium
15	0-3	0-2	0-2	1	0-1	0	0	0-1	0	0	Poor

Both donor eleven and fourteen had samples of grade 3 and even grade 4 in the case of day 7 but these donors also had several negative samples with no development at all. All the other donors were rated as poor as the highest grading found was 2, though the majority were 1 and 0. Interestingly, donor fifteen had some identifiable samples (grade 2 and 3) though these were only on days 1 – 3 and this may be due to more residues sitting on the fabric surface and therefore available for the VMD treatment to visualise, whereas the residues on the other days could have been absorbed.

Therefore, the mixture of synthetic and natural fibres in this fabric seems to have improved the ability of the fabric to hold fingerprint residues on the surface, which renders them available for VMD to visualise these marks. The detail observed was not as high as other fabrics in this group of studies; however, this could be due to the rougher surface negatively affecting the visualisation.

7.9.3 Polyester

Table 7.7: Polyester VMD donor rating and range of donor fingermark gradings for each illustrating the effect of age on the ridge detail visualised on the samples.

Donor	Day										Donor rating
	1	2	3	4	5	6	7	14	21	28	
1	1-4	0-4	1-3	0-3	2-3	2-3	1-4	1-3	1-2	1-2	Medium – Good
2	3-4	2	1	0-3	1-3	1-2	1-3	1-2	1-2	1	Medium
3	0-1	0-1	1	0-1	0-2	1	0-2	1-2	1	0-1	Poor
4	2	1-2	1	1	0-1	1	0-1	0	0	0-1	Poor
5	1-4	2-3	0-2	0-1	1-4	0-1	0-2	1-2	2	1-2	Medium
6	1-3	0-1	1	1	0-1	1	0-2	0-2	0-1	0-1	Poor - Medium
7	0-1	0	0-1	0-1	0-1	0-1	0-2	0-1	0-1	0	Poor
8	0-1	1	0-1	0-2	0-1	1	0-1	1	0-1	1	Poor
9	0-1	2-1	1-2	0-2	1-2	0-2	0-2	0-2	0-1	0-1	Poor - Medium
10	0-1	1	0-1	1	1	1-2	1	0-2	0-1	1	Poor - Medium
11	1-3	1-2	1	1	0-2	0-2	0-1	2	0-1	1-2	Poor - Medium
12	1-3	0-2	1	0-1	0-1	0-1	1-3	0	0	0	Poor - Medium
13	1-3	2-3	0-2	1-2	0-3	0-1	1-3	1-2	0-1	1	Medium
14	1-2	2-3	1-2	0-1	0-2	1-2	1-3	1	0-1	2	Medium
15	0-2	0-1	0-2	0-2	0-2	0-1	0-1	1-2	0-1	0	Poor - Medium

Polyester only had four donors (three, four, seven and eight) rated as poor and, 7 out of 160 samples graded as 2. There were also more donors (six, nine, ten, eleven, twelve and fifteen) rated as poor to medium and these had more samples graded at 2. The medium donors had more identifiable marks deposited and visualised, therefore on this fabric donor two, five, thirteen and fourteen were better at depositing higher levels of fingerprint residues or, alternatively, polyester absorbed less of the residues. The residues not being absorbed is the more likely of the two explanations when you compare this fabric and the levels of fingermark detail observed from each donor to cotton and polycotton discussed above.

The mixture of fingermark grades and donor ratings illustrates that the polyester used by each researcher have different smoothness due to variability in weave structure. This influenced the results and if all the researchers had used the same smoother polyester there may have been higher fingermark gradings overall. However the fact that this was not the case also reflects the real world and the various uses (e.g. clothing ranging from silky dresses to rough more open weave shirts), surface structures and type of weave.

7.9.4 Satin

Table 7.8: Satin VMD donor rating and range of donor fingermark gradings for each day illustrating the effect of age on the ridge detail visualised on the samples.

Donor	Day										Donor rating
	1	2	3	4	5	6	7	14	21	28	
1	1-2	1	2	1	1	1	1-2	1	1-2	1	Poor
2	1	1	1	1	1	1	1	1	1	1	Poor
3	1	0-1	0-1	0-1	0	1	0	0	1	0-1	Poor
4	0-1	1	0	0-1	0-1	0	1	0	0	1	Poor
5	1	0	0-1	0	0	0-1	0	0-1	0-1	0	Poor
6	0	0	0	0	0-1	0	1	0	0	0-1	Poor
7	0-1	0	0	0-1	0-1	0	0-1	0	0	0	Poor
8	0	0	0	0	0	1	0-1	0	0	0-1	Poor
9	0-1	0	0	1	1	0-1	0	0	0	0–1	Poor
10	1	0	0	0	0	0	1	0-1	0	0	Poor
11	0-1	0-1	1	1	1	1	0-1	0-1	0	0-1	Poor
12	1	0-1	0-1	1	0-1	0	0-1	0	0	0	Poor
13	0-1	0-1	0-1	1	0-1	0-1	1	0	0	0-1	Poor
14	1	1	1	0-1	1	1	1	0	1	1	Poor
15	0	0	0	0-1	0-1	0-1	0	0	0-1	0	Poor

Satin was another fabric that performed poorly with only donor one having a grade of 2. All donors were rated as poor as the majority of samples showed no marks or areas to indicate a touch, though some donors that did have positive samples at grades 1. It would have been expected, as this fabric had a smooth surface and a tight weave, that there would have been more samples with ridge detail. This was not the case so there must be other factors influencing the results, such as a coating on the fabric's surface preventing the fingerprint residues from adhering or that the residues were quickly absorbed into the fabric leading to little or no development from the VMD process.

7.9.5 Nylon

Nylon showed the greatest level of fingermark detail and the highest number of good and medium to good rated donors. It also appears as if the detail obtained was consistent for each donor with the exception of donor two, as all the other donors received the same grade from each researcher. However, donor two who had a range for each day and in the case of days 7 and 21 this ranged from grade 1 to 4, again showing the variability of donors and the residues they produce. Overall, even with the higher levels of detail, the rating of the donors do seem to follow the pattern displayed with the other fabrics – poor donors are still poor, whereas the better donors, for example donor one is still the best and highest rated donor.

Table 7.9: Nylon VMD donor rating and range of donor fingermark gradings for each day illustrating the effect of age on the ridge detail visualised on the samples.

Donor	Day										Donor rating
	1	2	3	4	5	6	7	14	21	28	
1	3	4	3	2	4	3	3	4	2	2	Good
2	2-4	1-2	2	2-4	3	2	1-4	1	1-4	2	Medium
3	1	1	2	2	2	1	2	1	1	0	Poor
4	3	3	2	1	1	2	2	1	1	1	Medium
5	2	3	2	4	3	3	3	1	1	1	Medium – Good
6	3	2	3	1	2	2	2	2	1	2	Medium
7	2	1	2	1	1	1	1	0	1	0	Poor
8	1	2	1	1	3	2	1	1	1	2	Poor
9	1	2	1	1	0	1	2	1	1	1	Poor
10	1	2	1	2	1	2	2	1	1	1	Poor – Medium
11	3	0	3	3	2	2	0	1	1	2	Medium
12	2	1	1	1	1	2	1	1	1	1	Poor
13	2	2	2	2	1	1	2	2	1	0	Poor – Medium
14	3	2	4	2	3	1	2	2	4	1	Good
15	0	3	2	3	1	2	3	2	2	1	Medium – Good

This increase in detail and marks observed is most likely due to the surface of the nylon being smooth and the weave being quite tight. In addition, the lack of porosity of this fabric would allow the fingerprint residues to remain on the surface and therefore be freely available for visualisation during the VMD process.

7.9.6 Silk, Lycra, linen and PVC

Fewer researchers used silk, Lycra, linen and PVC in their studies so the results were combined to give an overview as to the fingermark visualisation ability of these fabrics. Silk was the highest donor rated fabric (medium) and contained the most fingermark detail as would be expected since silk is smooth and has a relatively tight weave. Lycra is another example of a tight weave fabric, however it was not as smooth as the silk and the stretchy nature of the fabric may have resulted in the grab or push opening up the weave as it was held and therefore the residues do not remain on the surface, but are forced into the fabric. PVC is also quite smooth, however very little detail was observed so, again, this could be due to the surface coating as stated by Ramotowski (2013, p. 77) "heavily plasticized" PVC did not develop many marks and had "little success". Linen was also rated as poor donor-wise and had a fingermark rating of 1 for all days, except day 1; this would be expected from the open weave and quite rough surface of linen.

Table 7.10: VMD Donor rating and range of donor grading for donor one, for each day on silk, Lycra, linen and PVC demonstrating the effect of age on sample).

Fabric	Day						Donor rating
	1	2	3	4	7	21	
Silk	2	2 -2	2 - 4	4	2 -4	1	Medium
Lycra	1	1	1	1	1	0	Poor
Linen	0	1	1	1	1	1	Poor
PVC	0 -1	0	1 - 2	1	1	0	Poor

Overall, when considering donor ratings, nylon produced the best development as it was the only donor to show good ratings (donor one and fourteen). Nylon had the highest number of excellent ratings (4) and donors with good to medium gradings (53 % of the donors for nylon). The other fabrics were lower in their donor gradings - polyester (33 % of donors rating medium to medium/good) and polycotton (13 % donors rating medium), though with some donors (nine, twelve and thirteen) polyester was the same or better than nylon. Satin and cotton were always poor as virtually all their grade ratings were 0 or 1. However, donor one, who consistently produced better than average deposits, was an exception having a poor to medium rating due to this donor showing ridge detail on cotton [Table 7.5].

The effect of age on the samples and the ability of VMD to visualise impressions can also be seen in Table 7.5 – 7.10. It appears that the production of marks is independent of the age of the sample. Researcher two found that freshly planted marks in many cases contained too much oil therefore lead to empty marks, the samples that were between 3 and 7 days old had lost some of the oils and therefore produced the full range of gradings, while the oldest marks were mixed varying between no marks and excellent. This may of course been caused in part to the fact that this researcher was using loaded marks, which will contain higher than expected levels of secretions, due to the addition of oils from the forehead and/or from behind the ear (Kent 2010). Researcher three found similar levels of development on each day, however some previously unseen ridge detail was observed on two samples that were re-examined a few days later. Researcher three also used the loaded method of deposition; therefore this could have impacted on the results obtained, however researcher one used the natural method of deposition and found that there was an even spread between days and donors. With the natural deposition method it was found that the early impressions produced better detail than the loaded method samples which reinforces the idea that the loaded method adds too much oil to the hands before donations, leading to the marks being overloaded and no detail visualised. There were also a few occasions where there was an unexpected lack of information, such as donor thirteen on polyester who had a rating of 3 on days 1 and 2, 2 on day 3, 1 on day 4, no development on 5 and 6, then back up to a 3 on day 7 and back down to 1 for days 14 – 28. This may be due to environmental or physical conditions, such as the donor being colder and therefore producing fewer residues. This may have been the case as polycotton was collected on the same days and produced similar ratings; in particular a 3 on day 1 and no development on days 5 and 6. Therefore the conditions were the same for the collection of both fabrics and thus may have affected the marks visualised.

7.10 Fingermark grading of fabrics visualised with VMD

A large number of the 1908 samples were graded as either 0 (815; 43 %) or 1 (793; 42 %) thus would not be helpful with identification as there is no ridge detail, but, many would give target areas for DNA collection. Figure 7.2 shows that there were 300 samples with grades 2 – 4 and these could help in identification due to the presence of ridge detail and/or palmar flexion creases.

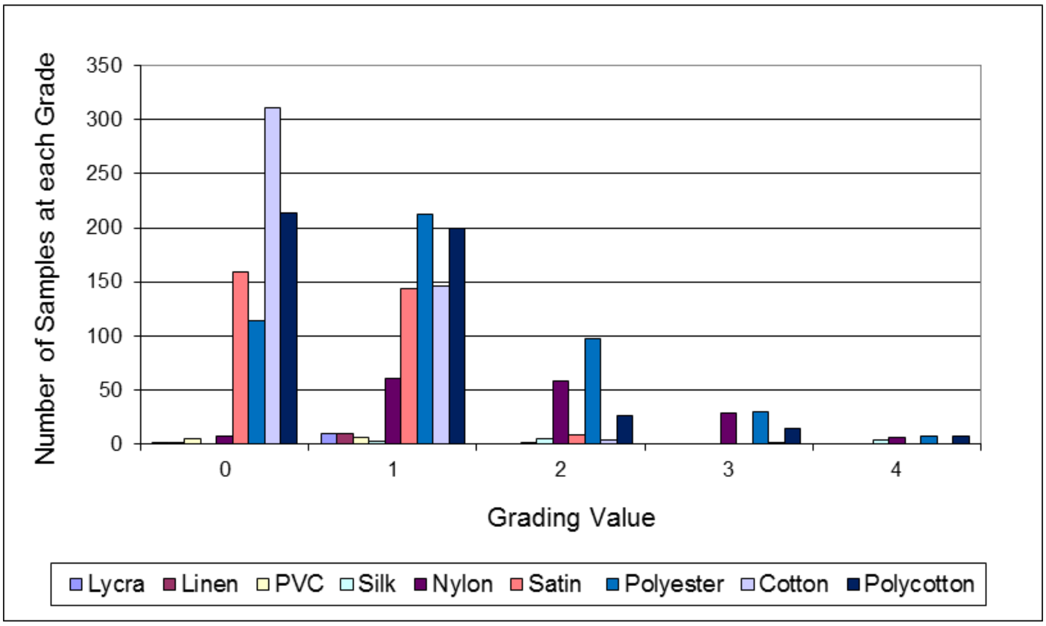


Figure 7.2: Combined grading of all donors in the study on each fabric type all visualised with VMD.

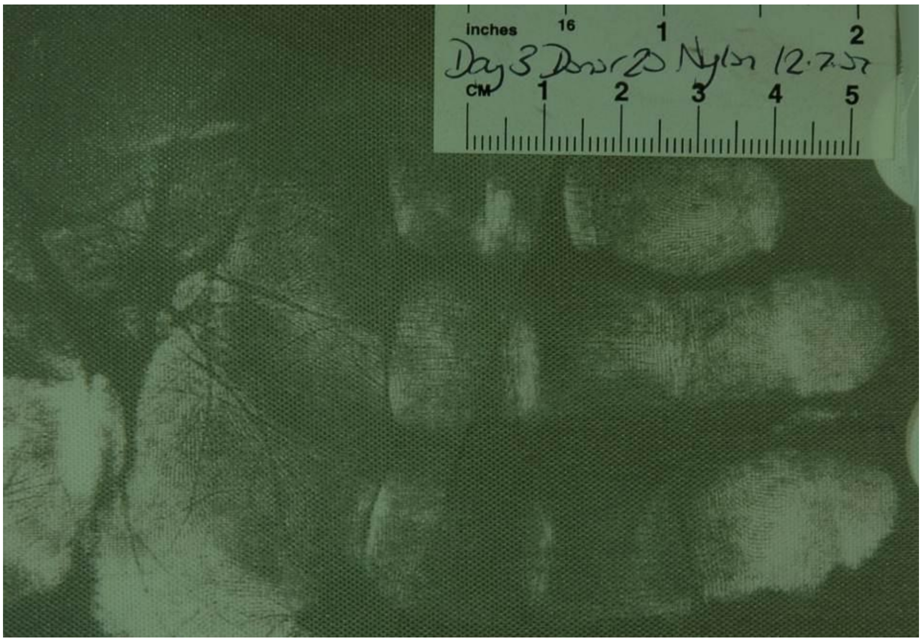


Figure 7.3: Close-up of a grab from donor twenty (day 3 on nylon), containing ridge detail and palmar flexion creases. Photographed using a Nikon D40 and white light.

When considering the fabric types they can be ranked on the ability of VMD to visualise detail (ratings 3 and 4) as follows: silk, nylon [Figure 7.3], polyester, polycotton, cotton, satin, PVC, Lycra and linen. Silk, nylon, polyester and polycotton all had samples with grade 4 ratings, but cotton only had one grade 3 and four grade 2 samples. However, satin had nine grade 2 samples and PVC had one grade 2 sample with all the other fabrics being grade 1 or 0. If ratings of 2 are taken into consideration the order is nearly the same: silk, nylon, polyester, polycotton, PVC, satin, cotton, Lycra and linen, with only cotton and satin having switched order.

It is thought that polyester would have had more higher-ranking samples if researcher 1 had used a shinier fabric, the one used during this trial was quite matt in appearance and did not have such a smooth surface compared to the other polyester fabrics used. Also, polyester usually has some sort of waterproofing or coating, as do some other fabrics, which may be removed through washing, therefore may have had some effect on the results as not all the polyester fabric samples were washed prior to testing. However, in many assault cases clothing may not have been washed prior to wearing. Therefore, the inclusion of fabrics that had not been washed prior to testing was thought to be sensible to allow for a realistic comparison.

Overall, it appears that the manmade fabrics tend to allow more ridge detail development; for example, nylon and polyester consistently produce more than the natural fabrics such as cotton and silk. This could be due to the fingerprint residues being less likely to be absorbed or perhaps, evaporating off the fabric. There does also appear to be a link between the fabric type and shininess of the fabric. Polyester (7 samples) and nylon (6 samples) had the highest donor and ridge detail ratings (and as previously stated it is thought that polyester would have allowed more to be developed if researcher 1 had used a shinier fabric), followed by silk (4 samples). However, with the particular sample of satin used by these researchers the opposite was observed. Even though it was an extremely shiny fabric, fewer high ratings were seen perhaps because the shininess could have actually masked any ridge detail.

The amount of detail visualised is dependent on the fabric being examined, as well as the environmental conditions in which the marks were "laid". For example, with good donor one, the chance of VMD visualising enough detail to lead to identification is quite high. Though this donor did not always leave impressions that would produce identifiable detail (ratings 0-2) there were more days and fabrics that were successful than were not. On satin, this donor was the only one to produce a rating of anything higher than 1; on days 1, 3, 7 and 21 there was a rating of 2 which contained some detail, though possibly not enough to lead to an identification. On cotton, this was the only donor to produce any ridge detail though this was only on a fresh, day 1 sample. This emphasises that this is a good donor and that cotton is a poor fabric that does not allow ridge detail to be produced [Figure 7.4].

Figure 7.4: Example of a grab from donor seven (day 1 on cotton) containing palmar flexion creases and empty marks, thus no ridge detail. Photographed using a Nikon D40 and white light.

Considering the best three fabrics (polyester, nylon and polycotton) there was a range of ratings within most days, but with donor one there was a considerable number of ratings at 3 or 4. Polyester showed more 0, 1 and 2 ratings but this fabric had ratings of 3 or 4 on eight out of the ten days tested, with only the later days (21 and 28) producing either ratings 1 or 2.

With nylon, donor one had the same ratings for all three researchers [Table 7.9] though this time there were three days with a rating of 2, but no 0 or 1 ratings therefore around a 70 % chance of visualising ridge detail with this donor. Finally, polycotton only had one 0 rating (one of the day 21 samples) with the rest of the days having ratings of 3 and 4. The range of ratings within each day, with the exception of nylon for all donors except donor two, demonstrates that the physical and environmental conditions have an effect on the donations and therefore the detail visualised by VMD. This is reinforced by considering one of the poor donors (donor seven). Cotton, polycotton and satin only had ratings that showed touches but no detail (0 and 1 ratings); polyester was the same with the exception of day 7 that had a 2 rating; and finally nylon where this donor had two days with rating 2. There were no days that had ratings that would lead to identifiable detail. Therefore, this donor's poor ability to leave good deposits reinforces the theory that there are many physical conditions, such as increased secretions due to exercise, excitement and fear or naturally having dry skin that change the ability of donors to leave impressions that can be visualised by VMD.

7.11 Target areas visualised by VMD

Table 7.5 shows that all the fabrics displayed target areas, from 20 % in the case of day 6 (cotton) to 84 % in the case of day 3 (polyester); some were only fingertip marks but others showed full hands. Therefore the more detailed hand marks [Figure 7.6] could help lead to identifications or at the very least exclude or include a suspect. Here polyester had samples that developed target areas over the full timeline ranging between a low of 16 % of the samples on day 28 to a high of 49 % on days 1 and 2. All these target areas could also help lead to a "picture of events" – does the impression indicate a gentle hold or touch or a forceful grab or push indicative of the complainant's or suspect's sequence of events?

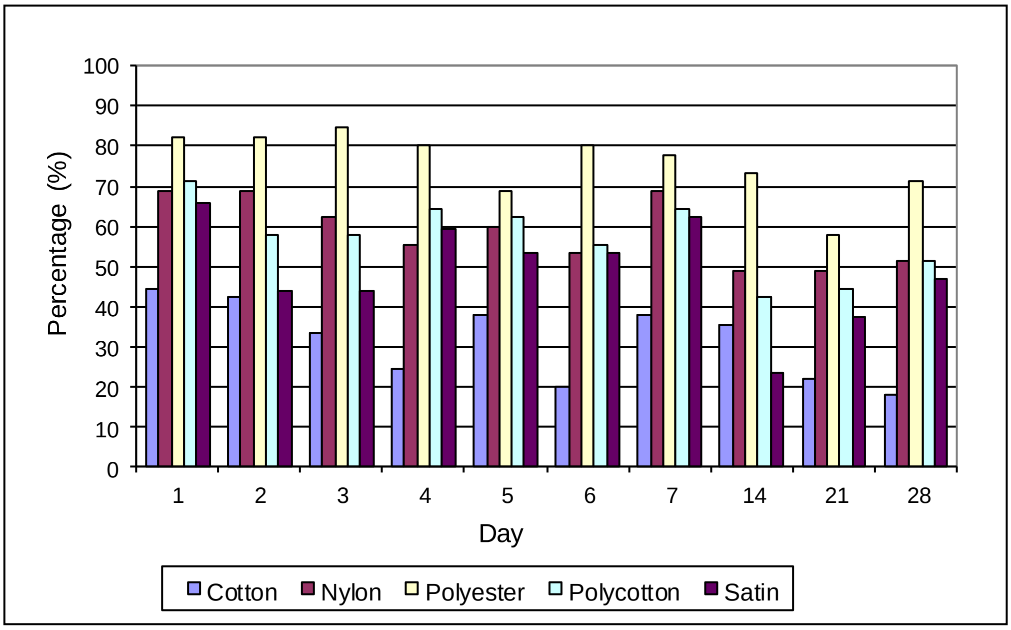


Figure 7.5: All fabric samples from every donor (1 – 20) from all days containing target areas ranging from fingertip impressions to full hand impressions.

Not every mark visualised by the donors contained ridge detail, therefore the marks could not be used for identification purposes, but this section investigated the use of empty marks as target areas for DNA and as a possible means of determining a sequence of events.

All these marks could also be used as an area to target for DNA and as the Home Office fingerprinting protocols and the work carried out in conjunction with Ignacio Quinones (Quinones, I. 2012. pers. comm., 15 March) suggests that VMD does not affect the collection of DNA therefore the development of DNA profiles could be possible. Thus even if ridge detail is not developed it can aid targeting a garment for DNA, which in turn may lead to an identification.

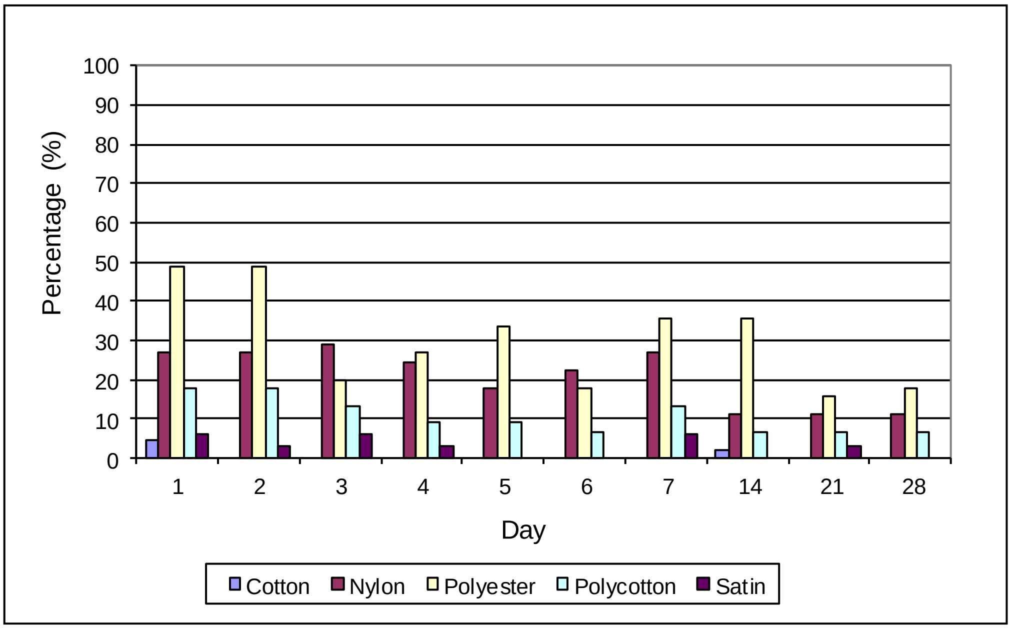


Figure 7.6: All fabric samples from every donor (1 – 20) from all days containing target areas containing ridge detail and palmar flexion creases.

7.12 The effect method of sample donation has on fingermark visualisation with VMD

Figure 7.7 shows the results of two different methods (grab and push) for sample donation. These methods of donation were used to simulate the actions an individual would use during an attack or assault. On first impressions it seems there is little difference between either method – some fabrics produced an even 50/50 spilt (polycotton and silk) with other samples diverging from the 50/50 split by a range of 2 % (polycotton) to 18 % (Lycra).

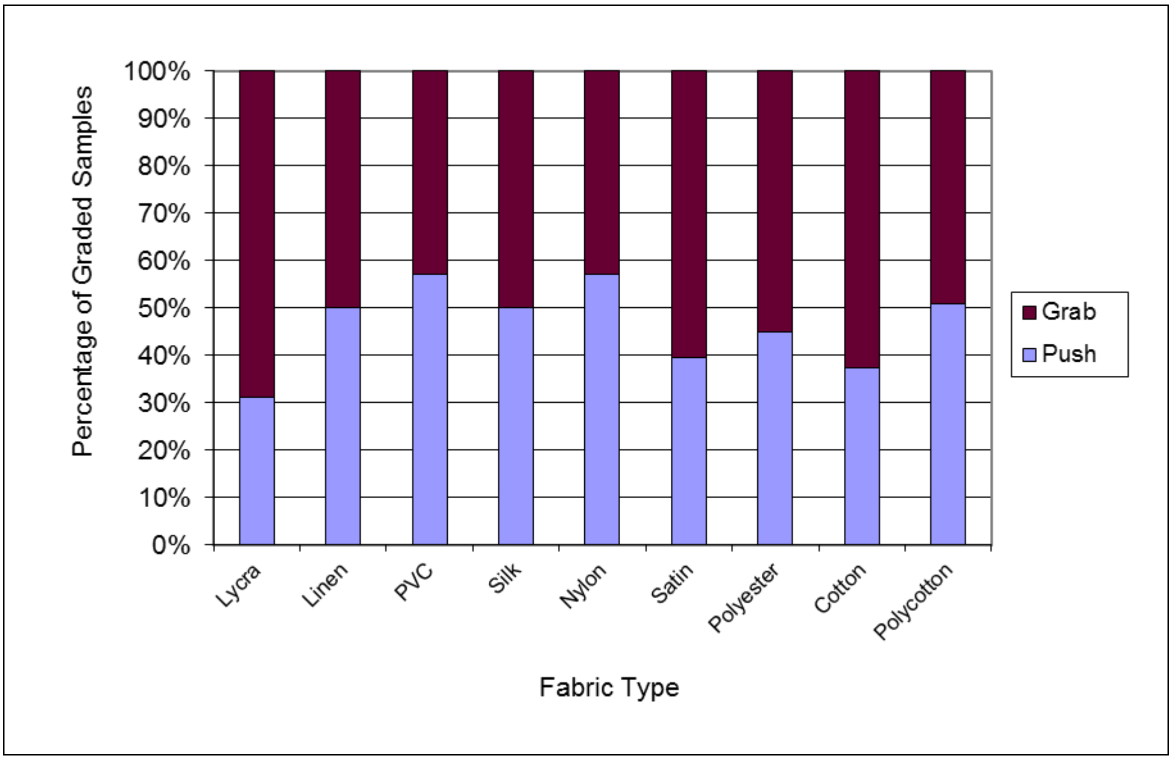


Figure 7.7: Comparison of grab versus push method of deposition visualised with VMD. Visible marks were graded 1 to 4. (Data from researcher 1 has been removed to prevent results appearing skewed as only grab samples taken).

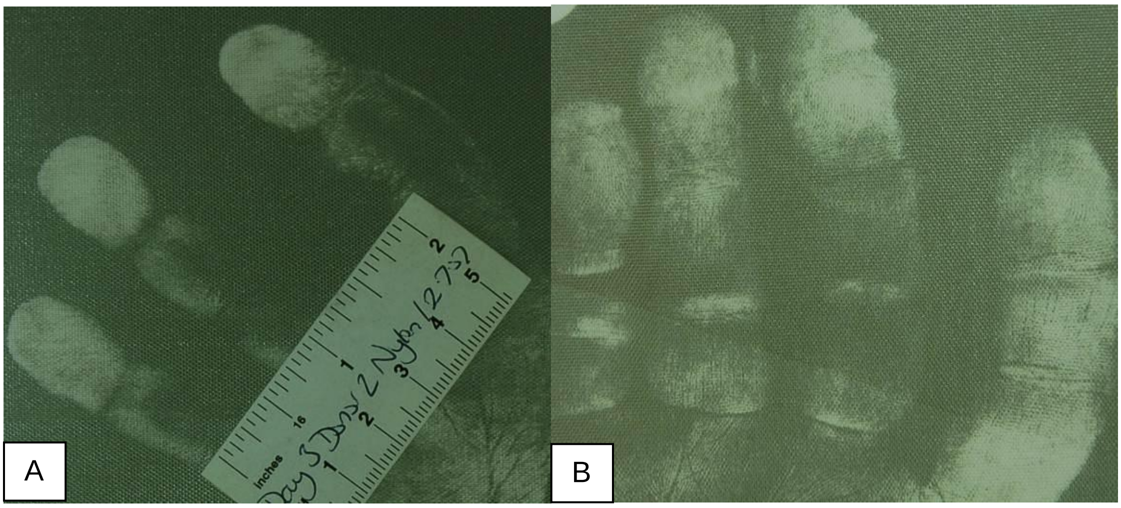


Figure 7.8: (A) Example of a push deposition on nylon visualised with VMD and (B) a grab deposition on nylon visualised with VMD, demonstrating the differences in appearance between a push, with its straight thin fingers and a grab with the bent fingers and a wider appearance (Streets 2009).

The main observation from the method of deposition seems to be that push deposits tended to produce better ridge detail in the fingers, whereas grabs produce better detail in the palm. This may be due to the nature of the hold as pushes lead to more pressure on the fingers, whereas a grab may put more pressure onto the palm, therefore lead to more detail in these areas. There is also a difference in the overall appearance of the shape of the fingers with the different types of depositions as illustrated in Figure 7.8 above. With pushes the hands tend to be held with the fingers open and flat which leads to fingermarks that appeared thinner and straighter when visualised. With grabs the hand is held in an open fist shape and the fingers are curved, which leads to fingermarks that appeared thicker and more bent. This variation in appearance and level of detail is mostly likely being due to the nature of the hold. For example, pushes lead to more pressure and contact from the fingers, whereas a grab may put more pressure onto the palm. This in turn would explain why there were differences in areas of detail visualised as well as the shape of the fingers and why the grab and push appear different to each other. This type of information could therefore aid in an investigation, if it can be used to determine the sequence of events, possible force used and type of action and hand position used during an altercation.

A Chi-squared test was carried out to determine statistically whether there was a relationship between the deposition method (grab or push) and the grade assigned to the level of ridge detail obtained. The null hypothesis (H_0) is that there is no difference between the method of deposition (grab or push), and the alternative hypotheis (H_A) that there is a difference between the deposition method.

The p-value in this case was <0.001, which means the H_0 should be rejected and that there is a difference between the two deposition methods.

The residual values in Table 7.11 indicate that the grab method of deposition was observed less often at grade 0 than expected with an actual count of 531 compared to the expected count of 534.6. The push method was observed more often than expected with an observed count of 283 compared to the expected count of 279.4. At grade 1, the grab method showed comparable results, with the grab having a lower count (482) than expected (512.9), while the push method was the opposite with a higher count (299) compared to an expected count of 268.1. However, at grade 2 and 3 the opposite is true with the grab method having a higher experimentally observed count, the statistically calculated expected count. However, the push method showed the opposite trend. With grade 4, the frequency of the methods reversed once more, with the grab being observed less often, however at this grade the difference was quite small, at only 0.7. Therefore, it could be stated that grab method showed most indications of the fabric being touched and a good level of ridge detail with the push method having a higher level of ridge detail.

Table 7.11: Chi-squared test results comparing the grades (0 - 4) observed for the grab and push technique of planting latent marks on nine fabrics visualised using VMD. The actual count obtained, the expected count, the percentage of each technique at each grade, as well as the residual values are given.

Grade		Grab	Push	Total
0	Count	531	283	814
	Expected count	534.6	279.4	814.0
	Percentage with grade (%)	65.2	34.8	100
	Residual	-3.6	3.6	
1	Count	482	299	781
	Expected count	512.9	268.1	781.0
	Percentage with grade (%)	61.7	38.3	100
	Residual	-30.9	30.9	
2	Count	164	48	212
	Expected count	139.2	72.8	212.0
	Percentage with grade (%)	77.4	22.6	100
	Residual	24.8	-24.8	
3	Count	57	14	71
	Expected count	46.6	24.4	71.0
	Percentage with grade (%)	80.3	19.7	100
	Residual	10.4	-10.4	
4	Count	19	11	30
	Expected count	19.7	10.3	30.0
	Percentage with grade (%)	63.3	36.7	100
	Residual	-0.7	.07	
Total	Count	1253	655	1908
	Expected count	153.0	655.0	1908.0
	Percentage with grade (%)	65.7	34.3	100

A comparison of natural versus loaded deposition was also undertaken. In the case of natural fingerprint deposits, the donors were asked not to wash their hands for approximately 45 minutes prior to donations so their natural fingerprint deposit levels would be captured. In the case of loaded deposits the donors rubbed their fingers over their noses, forehead and behind their ears, then rubbing their hands together to give an even (though not natural) level of deposits.

When these were compared [Figure 7.9] it would appear, even though the loaded method had over twice as many samples, that loaded deposits tend to produce more 0 graded results, ranging from no development to possible target areas for DNA.

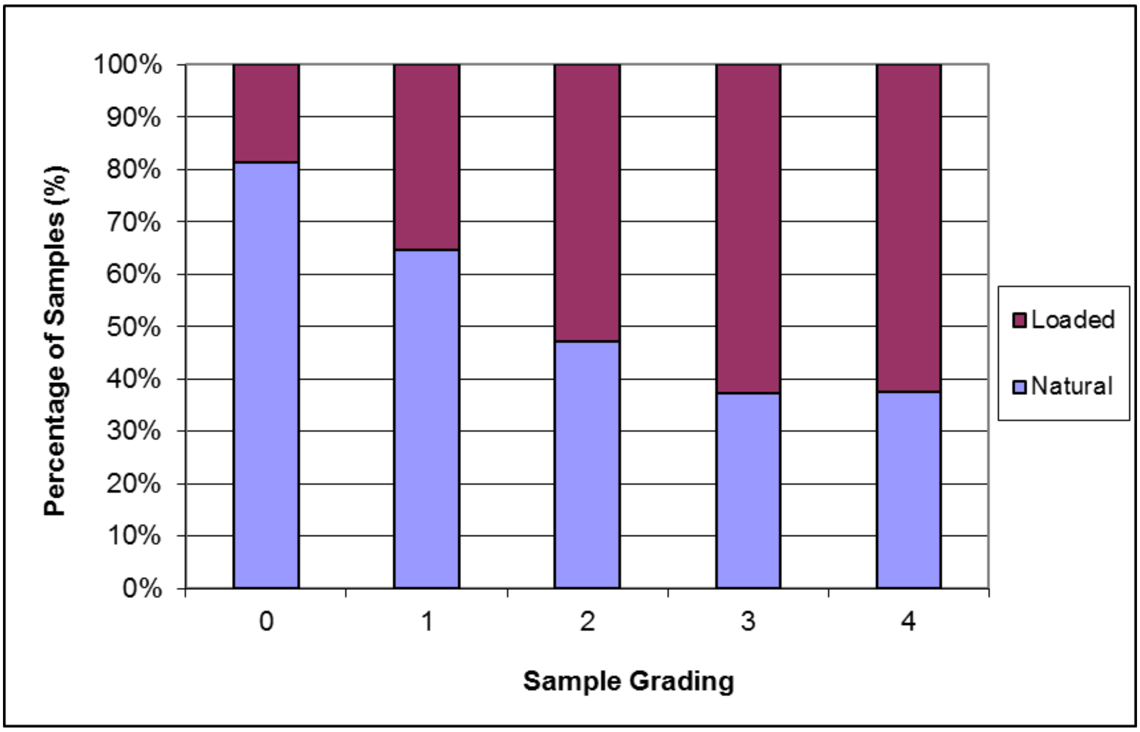


Figure 7.9: Percentage of samples for each grade (0 – 4) when comparing "natural" versus loaded method of deposition on all fabric types (Lycra, linen, PVC, silk, nylon, satin, polyester, cotton and polycotton). Loaded (1308 samples) versus Natural (600 samples).

When ridge detail was observed, however a natural deposit produces more ridge detail than the loaded marks. This may be due to loaded marks having too high a level of fingerprint secretions therefore obscuring ridge detail when deposited whereas the natural marks may not have enough to consistently leave ridge detail but are less likely to obscure ridge detail. This is expressed by Kent in his 2010 paper about standardising protocols for testing fingerprint reagents when he comments that "grooming" or loading of marks can increase the levels of fatty materials in the marks by as much as 50 times compared to a mark that has not had any extra residues added. This can make the reagents look as if they are better or more effective than they would usually and that with some of the more sensitive techniques it can cause an overloading effect and there will be no ridge detail and only an outline of where the marks had been planted. For example, in the case of VMD the loading of marks can cause the valleys to be filled which can prevent deposition of the metals. Therefore Kent suggests that loaded marks should not be used and only the rubbing of the hands together prior to planting to evenly distribute the residues should be done. The amount of fingerprint secretions either loaded or natural is of course dependent on the donor, for example a poor donor, such as seven, left poor marks whether they deposited loaded or natural marks.

A Chi-squared test was carried out to determine statistically whether there was a relationship between the treatment used (loaded or natural) and the grade obtained. The null hypothesis (H_0) is that there is no difference between the method of deposition (loaded or natural), and the alternative hypotheis (H_A) is that there is a difference between the deposition method. The p-value in this case was <0.001, which means the H_0 should be rejected and that there is a difference between the two deposition methods, so H_A should be accepted.

Table 7.12: Chi-squared test results comparing the grades (0 - 4) observed for the loaded and natural technique of planting latent marks visualised with VMD. The actual count obtained, the expected count, the percentage of each technique at each grade and the residual values are given.

Grade		Loaded	Natural	Total
0	Count	663	152	815
	Expected count	558.7	256.3	815
	Percentage with grade (%)	81.3	18.7	100
	Residual	104.3	-104.3	
1	Count	513	280	793
	Expected count	54306	249.4	793.0
	Percentage with grade (%)	64.7	35.3	100.0
	Residual	-30.3	30.6	
2	Count	95	106	201
	Expected count	13708	63.2	210.0
	Percentage with grade (%)	47.3	52.7	100.0
	Residual	-42.8	42.8	
3	Count	28	47	75
	Expected count	51.4	23.6	75
	Percentage with grade (%)	37.3	62.7	100.0
	Residual	-23.4	23.4	
4	Count	9	15	24
	Expected count	16.5	7.5	24.0
	Percentage with grade (%)	37.5	62.5	100.0
	Residual	-7.5	7.5	
Total	Count	1308	600	1908
	Expected count	1308.0	600.0	1908.0
	Percentage with grade (%)	68.6	31.4	100.0

From Table 7.12, the residual values indicate that the natural samples were observed less often at grade 0 than expected with an actual count of 152 compared to the expected count of 256.3, whereas the loaded samples were observed more often than expected having an observed count of 663 compared to the expected count of 558.7. The opposite was true with the remaining grades (1 – 4) where the natural technique was observed more often than expected and the loaded method was observed less often than expected. The biggest difference is seen for grade 2 with the actual natural count being 106, whereas the expected count was 63.2. Though the difference with the other grades was not as large, they were all higher than expected, which means that the expected counts of all the loaded marks were lower than expected.

This means that the technique of using natural prints to plant marks led to less zero graded marks, more visible marks and more marks that contained ridge detail. Thus, the natural technique is more effective at leaving marks on fabric that can be visualised with VMD and contain more ridge detail compared to the loaded technique. Therefore, the conclusion is the same as previously discussed on page 159 and reinforces the opinion that natural and not loaded prints should be used when carrying out fingermark research.

7.13 Effect of metal type used during VMD on visualised fingermarks

The final comparison made during this study was between the metals utilised during the VMD process - a single metal (silver) and the more commonly used two metals (gold + zinc) on cotton, polyester and polycotton [Figure 7.10, 7.11 and 7.12].

Figure 7.10 shows that, for cotton, gold + zinc seems to produce more ridge detail leading to gradings of 2 and 3 with silver only leading to 0 or 1 gradings. Therefore, with cotton it would be more sensible to use the gold + zinc method to visualise marks, as this has visualised the most detail in this study. This increased detail may be due to the gold producing anchor points for the zinc, thus making the detail more visible, whereas the silver only attaches to silver already deposited so there may be less attachment and contrast, therefore less visualisation of detail.

With polyester [Figure 7.11] the split was even for 0 – 3 ratings, but only gold + zinc producing any 4 gradings. Therefore, to visualise higher levels of ridge detail it appears that gold + zinc is the process to choose. However, both metal choices work quite well, therefore choice of which metal(s) to use may be down to the colour of the fabric being processed. For example, silver is easier to see on darker fabrics as it appears silver in colour, whereas the gold + zinc appears grey in colour, so it not as obvious on darker fabrics.

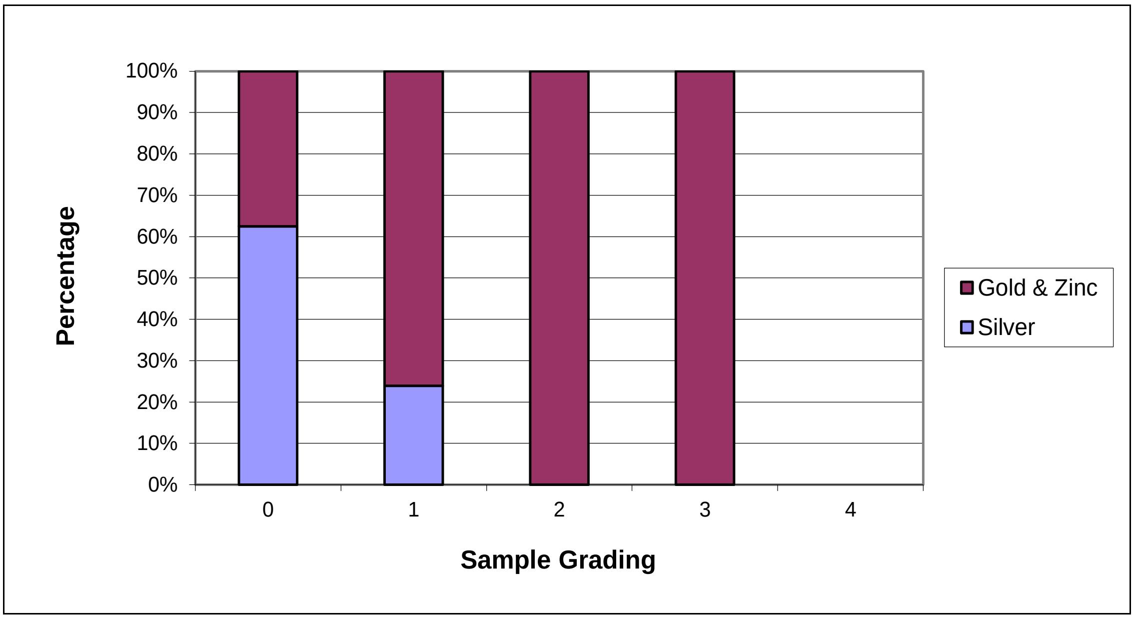


Figure 7.10: Silver versus gold + zinc use in VMD on cotton fabric, demonstrating the spread of ridge detail visualised.

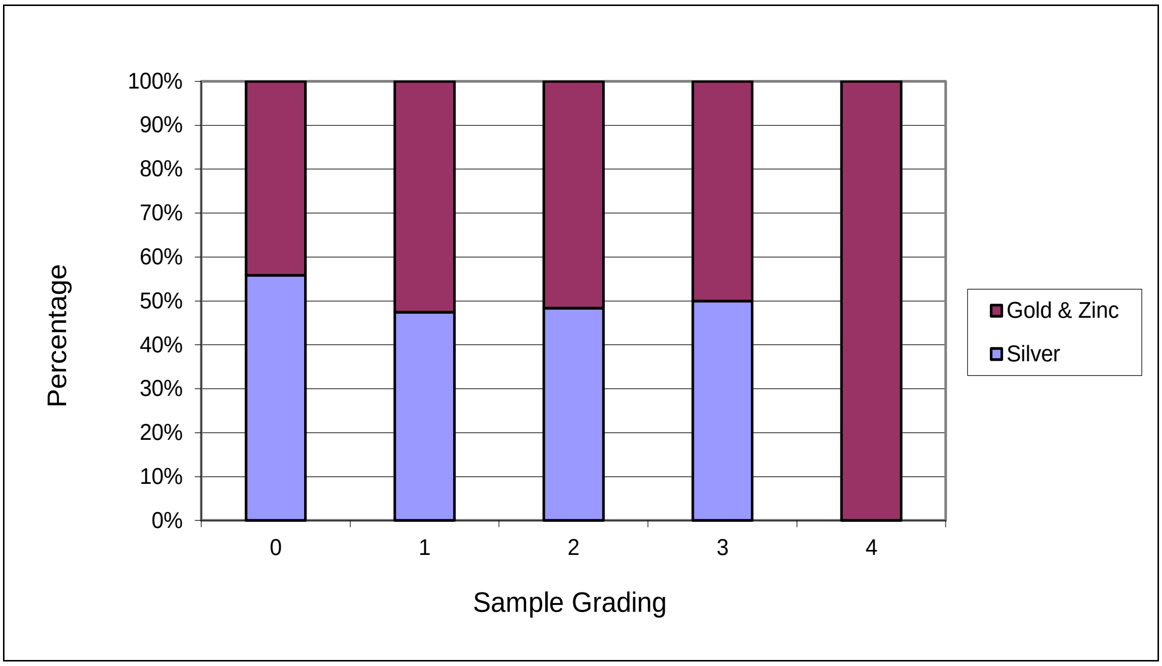


Figure 7.11: Silver versus gold + zinc use in VMD on polyester fabric, demonstrating spread of ridge detail visualised.

Finally, with polycotton [Figure 7.12], again silver led to less positive marks only grade 1 with the majority of the samples being negative (grade 0), while gold + zinc showed the full range of gradings from 0 to 4. Thus, it would appear that the gold + zinc process is more effective at allowing the development of ridge detail on polycotton and would be the metals to choose if the article being processed was composed of polycotton.

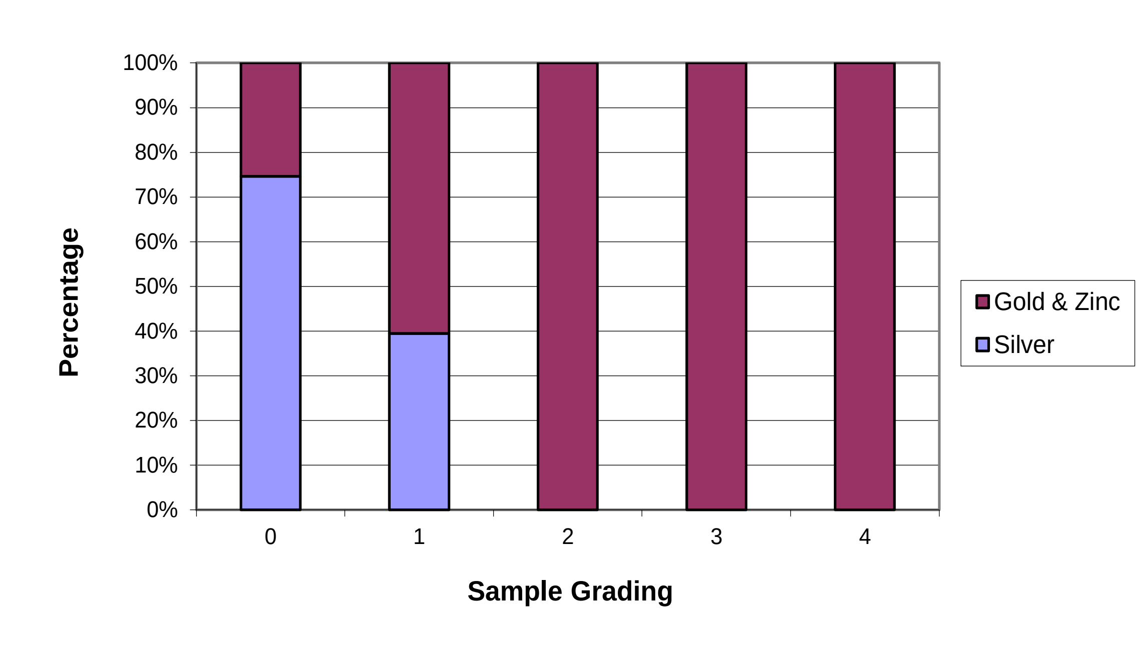


Figure 7.12: Silver versus gold + zinc use in VMD on polycotton fabric, demonstrating spread of ridge detail visualised.

Overall, it appears that different fabrics show varying levels of ridge detail depending on the metal(s) used during VMD. However, as only three fabrics were processed with gold + zinc and silver VMD, more work needs to be carried out to determine which should be used for each different fabric type commonly encountered in modern clothing and operationally in relation to crimes.

7.14 CAF Donor grading

The amount of detail visualised [Figure 7.13 and Table 7.10 – 7.15] and therefore the donors' grading appears to follow a similar trend to VMD. Once more, donor one consistently ranked in the higher end of the best results – good on silk, medium to good on nylon and satin, medium on nylon/polyester and PVC and poor on nylon-Lycra, viscose, linen and wool. One researcher included nylon/polyester and wool in their study, however as nylon/polyester was not found to be in common use and wool does not generally comply with the Home Office's three threads per mm rule, therefore these fabrics were excluded from the other studies. These donor gradings also reflect most of the results for VMD – Lycra and linen were poor; PVC however, produced a lower rating of poor with VMD compared to medium with CAF.

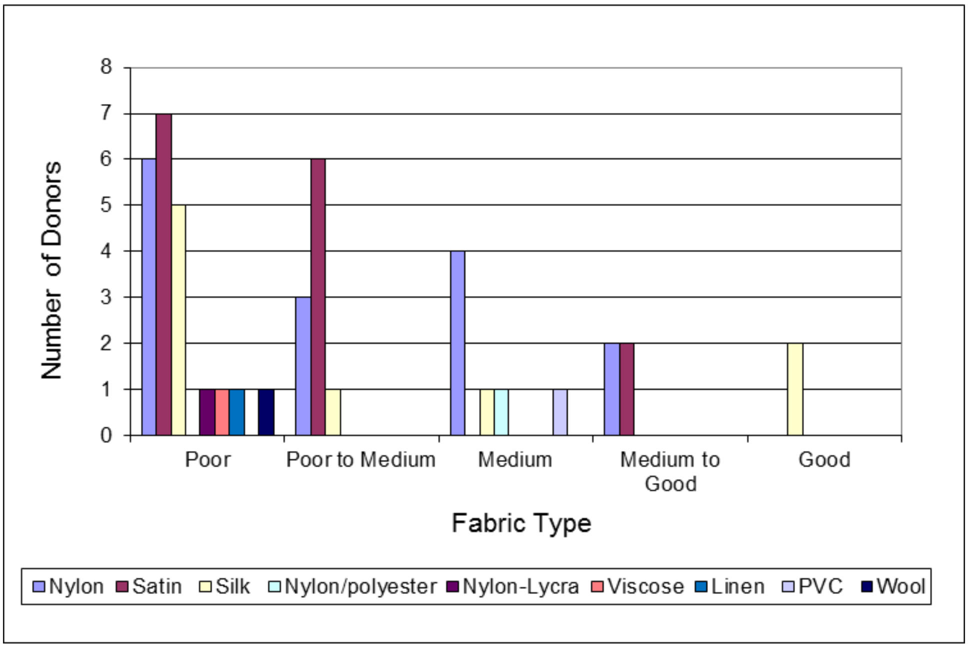


Figure 7.13: Grading of all donors, ranging from poor (donors who leave little or no detail or evidence that fabric has been touched) to good (donors who leave detail in fingertips and palmar flexion creases) , on all fabric types in all CAF studies in this section.

Therefore, with cyanoacrylate (CA) this donor could be considered medium to good overall and CAF could be considered a more suitable process for latent fingermark visualisation on PVC. Other donors were not as highly ranked, but donors two and fifteen could still be considered medium donors. Donor two showed the same results as donor one with the exception of silk where they were graded as poor and donor fifteen who was poor to medium on nylon and satin, however good on silk which increased their overall grading. The majority of donors fell into the poor to medium ranking due to most having a mixture of poor, poor to medium and medium gradings. The rest of the donors (four, six, seven and eight) were graded as poor on all of the fabrics tested. Both donor seven and eight were already considered as poor donors from past history and their VMD grading however donors four and six had previously been considered as good to medium donors. This reduction could be due to less residues being planted on these samples, a lack of visualisation due to background fluorescence from the BY40 staining, or the researcher's lack of skill in the CAF technique and determining the level of detail in marks visualised.

7.14.1 Nylon

Nylon can be seen to display the full range of fingermark gradings (0 – 4), thus illustrating that CAF is a suitable technique to visualise latent fingermarks. This high level of detail is most likely due to the low porosity of nylon, meaning the fingerprint residues are less likely to be absorbed into the fabric but reside on the surface and form a polymer with CAF. Also there is less absorption of the BY40 dye into the fabric which in turn means less background fluorescence and more visible detail.

Table 7.13: Nylon CAF donor rating and range of donor fingermark grading for each day illustrating the effect of age on the ridge detail visualised on the samples (grade 0 – 4).

Donor	Day										Donor rating
	1	2	3	4	5	6	7	14	21	28	
1	1-4	1-4	0-4	0-4	0-4	0-2	0-4	0-4	1-4	0-1	Medium – Good
2	0-2	1-2	0-4	0-2	1-4	0-2	0-4	2-4	1-4	1-4	Medium – Good
3	0-2	1-2	0-4	0-2	0-2	1	1	0-1	1-2	1-2	Medium
4	0-1	0-1	0-1	0-1	0-1	0-1	0-1	1	1-0	0-1	Poor
5	0-4	1-4	0-2	1-4	0-2	0-1	0-1	1	0-1	0	Medium
6	0-1	1	0-2	0-1	1	0	0-1	1	0-1	0-1	Poor
7	0-1	0-1	0-1	0	0	0	0-1	0-1	0-1	0-1	Poor
8	0-1	0-1	0-1	0-1	0-1	0	0-1	1	0-1	1	Poor
9	1	1-2	0-1	1	1	0	0-1	1	0-1	1	Poor
10	1	1-2	0-1	1	0-1	0-1	0-1	1	1	1	Poor
11	1	1-2	0-2	1-2	0	0	1	1	1	1	Medium
12	0	1-2	1	0-1	0	1	1	1-2	1	0-1	Poor – Medium
13	0-1	1-2	0–	0-1	1-2	1	0-1	1	0-1	1	Poor – Medium
14	0-2	1	0-2	0-2	1-4	1-2	0-2	0-2	0-2	0-1	Medium
15	0-1	1-2	0-1	1-4	0-1	0-1	0-1	1	0-2	1	Poor – Medium

Once more donor one had the most high fingermark grades, resulting in their overall medium to good donor grading. Every day, with the exception of days 6 and 28, have a grade 4 sample, illustrating again that this donor deposits good levels of fingerprint residues. With this many grade 4 samples it might be expected that this donor would have a good rating, however within the same day they also had 0 and 1 graded fingermark samples which explains the medium to good rating. Donor two also had a medium to good donor rating, though unlike donor one, they did not have as many grade 4 fingermarks. They also appeared to be less consistent with their deposits and therefore the grading each received The first day to have a grade 4 fingermark was day 3, when it was still quite fresh, but the remaining grade 4 fingermarks were on days 5, 7, 14, 21 and 28, so much older. This shows that the donor does have an impact on the level of fingermarks developed. However, the donor produces a variable amount of fingerprint residues and that the amount of residues must be influenced by several internal and external factors, such as diet, temperature and activity. The other donors were quite mixed with the levels of detail visualised with CAF. Only donors 3, 5 and 14 displayed any grade 4 fingermarks, with the majority of the donors having grade 2 as the highest fingermark grading. Overall the detail visualised on nylon was higher than the other fabrics in the studies.

7.14.2 Satin

With satin it was donor one again who had the highest level of detail – a grade 4 on day 1, with grade 2 and 3 fingermarks on days 2 – 4, 6, 14 and 28 giving this donor a medium to good donor rating. Donor two also had a medium to good rating and in some incidences had higher fingermark grading than donor one. This was seen on day 2, where donor two had a 3, so more detail than donor one with only a grade 2, as well as day 28 where donor two again had a fingermark grading of 3 while donor one was 1 to 2. This illustrates that donors can fall into general categories, but it does not mean that if they are good on one substrate or fabric that they will be good on all fabrics. The remaining donors were split between being poor to medium and poor donors – donors three, four, six, seven, eight, twelve and thirteen classed as poor with donors five, nine, ten, eleven, fourteen and fifteen classed as poor to medium. The difference between each group is down to the number of grade 2 samples, compared to the number of 1 and 0 grades. The poor donors comprised of individuals with very little evidence of contact, so only grade 0 or 1 samples, while the poor to medium donors had some extra detail (grade 2) and more indication of the fabric having been touched (grade 1).

Satin is a smooth fabric with a tight weave, therefore it would have been expected that more detail and thus higher fingermark gradings would have been observed. The lack of detail could not be blamed on the BY40 as there was less absorption with satin than with other fabrics, therefore the lack of visualised fingermarks and marks could be produced by the reflective nature of the fabric causing the detail to be missed or obscured. This reflection or some sort of coating of the fabric's surface seems to be the most likely explanation because if the BY40 was not absorbed to any great extent it would be expected that the fingerprint residues would then stay on the surface of the fabric rather than being absorbed and therefore available to form a polymer with the CA.

Table 7.14: Satin CAF donor rating and range of donor fingermark grading for each day illustrating the effect of age on the ridge detail visualised on the samples (grade 0 – 4).

Satin											
Donor	**Day**										**Donor rating**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**14**	**21**	**28**	
1	0-4	2	1-3	1-2	0-1	2-3	0-1	2-3	1	1-2	Medium – Good
2	0-1	3	0-1	2	0-1	2	1	2	1	3	Medium – Good
3		0			0			0		0	Poor
4	0-1	0	0-1	1	0-1	0	0-1	0	0-1	0	Poor
5	0-1	0	1-2	1	0-1	0	0-1	1	0-1	0	Poor – Medium
6	0	0	0	0			0	0	0	0	Poor
7	0	0	0	0	0		0	0	0	0	Poor
8	0-1	0	1	0	0-1	0	0-1	0	0	0	Poor
9	1-2	0	1	1	0-1		0-1		1	0	Poor – Medium
10	0-2	0	0-1	0	0-1	0	0-2	0	0-3	1	Poor – Medium
11	2	1	2	0	0		0	0	0	0	Poor – Medium
12	0	1	0	0	0		0	0	0	0	Poor
13	0-1	1	0-1	0	0-1	0	0	0	0-1	0	Poor
14	0-2	0	1	0	0-1	1	0-1	0	0	1	Poor – Medium
15	1-2	1	0-2	2	0-1	1	0-1	0	0-1	0	Poor - Medium

7.14.3 Silk

Silk is the only fabric in this section to have donors rated as good, because donor one and fifteen both had high fingermark grades (3 and 4) with fewer lower graded samples (0 and 1). Surprisingly, donor two performed extremely poorly on silk with only one day showing a grade 2 sample, while all the other days that were collected being graded as 0 or 1. It could be suggested that the days that were not collected or processed could have provided good detail, however the fresher samples that were collected and processed (days 1 and 3) had either no development or only an indication of the fabric being touched or, in the case of day 3, some palmar flexion creases. Therefore is seems that on silk this donor does not leave useful fingerprint residues or latent marks. Donor fifteen seemed to perform better on this fabric than those previously discussed with more higher fingermark grades, however again several samples were not processed so this could influence the final grade. The other poor donors were also poor with the other fabrics, with the exception of donor five who was rated as medium on nylon and poor to medium on satin.

Table 7.15: Silk CAF donor rating and range of donor fingermark grading for each day illustrating the effect of age on the ridge detail visualised on the samples (grade 0 – 4).

Donor	Day										Donor rating
	1	2	3	4	5	6	7	14	21	28	
1	0-3	0	0-2	0	2-3	1	0	0	0-3	0	Good
2	0-1		0-2		0-1		0-1		0-1		Poor
4	0		0-2		0-1		0-1		0		Poor
5	0		0-1		0		0		0		Poor
8	0		0-1		0-2		0		0		Poor
9	0-2		1-2		0-3		0-2		0-2		Medium
10	0-1		0-3		2-3		0-1		0-2		Poor – Medium
13	0		1-2		0-3		0		0		Poor - Medium
14	0		0-1		0		0		0		Poor
15	0-2		1-3		2-3		0-3		2-4		Good

Even though satin was smooth, with a tight weave, the results did not reflect the expected view that there would be more ridge detail observed on this fabric and that it would produce grades higher than 0 – 2. This could be due to the BY40, as the silk absorbed quite a lot of the dye and in turn was quite yellow; therefore any detail could have been disguised. This illustrates the need for an alternative dye to be found to dye CA polymer after fuming on fabrics.

7.14.4 Nylon/polyester, nylon-Lycra, viscose, linen, PVC and wool

The fabrics can also be ranked as to their ability to allow visualisation of impression. Silk [Table 7.15] was the only fabric to have any good donors and this may have been even higher if all days and donors had been used rather than just five time intervals (days 1, 3, 5, 7 and 21) and only ten of the donors (donors three, six, seven, eleven and twelve were missing). Even though donors six and seven were consistently poor, donors three, eleven and twelve ranged between poor and good to medium, therefore their inclusion in the silk trial may have led to further good or medium gradings. The other two fabrics were tested on all the days and donors and – it was found that nylon was the next best fabric [Table 7.13] as it has more donors ranking medium and above than satin [Table 7.14].

Table 7.16: CAF donor one rating and range of donor fingermark grading for each day illustrating the effect of age on the ridge detail visualised on nylon/polyester, nylon-Lycra, viscose, linen, PVC and wool (grade 0 – 4).

Fabric	Day									Donor rating
	1	2	3	4	5	6	7	14	28	
Nylon/polyester	2	2	1	2	1	2	1	0	1	Medium
Nylon-Lycra	0	0	0	0	0	0	0	0	0	Poor
Viscose	0	0	0	0	0	0	0	0	0	Poor
Linen	0	0	0	0	0	0	0	0	0	Poor
PVC	4	1	1	1	1	1	0	0	0	Medium
Wool	0	0	0	0	0	0	0	0	0	Poor

Table 7.16 can also be examined to see the effect of ageing of impressions on CA treated samples. All the donors had a few zero gradings on some of the days tested. However, on the same day a donor could also leave a mark that was graded as a 4 therefore there does not seem to be a significant effect on how long after the impression is laid as to when the best visualisation will occur. The grading seems to be more dependent on the donor’s mark leaving ability and fabric type. There are, however, a couple of interesting exceptions – days 6 and 28 with the former consistently producing the lowest grading. On nylon [Table 7.13] only three donors (1, 2 and 14) left an impression that was rated as a 2 with all other impressions either 0 or 1. On satin [Table 7.14] only donors one and two left marks graded higher than 1. With all other fabrics [Table 7.15 and 7.16] it was only nylon/polyester that produced a grading of 2 and the rest were 1 (silk and PVC) or 0 (nylon-Lycra, viscose, linen and wool). Day 28 had very little detail visualised on any of the fabrics tested with the majority of them only having 0 gradings. Silk was only tested with donor one with only one sample leading to a 0 grading whilst on days 1, 3, 5 and 21 higher gradings were observed.

7.15 Fingermark grading of fabrics visualised with CAF

Of the fabrics tested cotton, polyester, nylon-Lycra, viscose, wool and linen samples were all grade 0 [Figure 7.14], while all the other fabrics showed some marks ranging from 1 (no development) to 4 (excellent). In total, 1473 of the samples were graded 0, with 1826 being graded as 1, which means there were only 461 (12 %) samples visualised by CAF that could aid in identification through ridge detail and flexion creases.

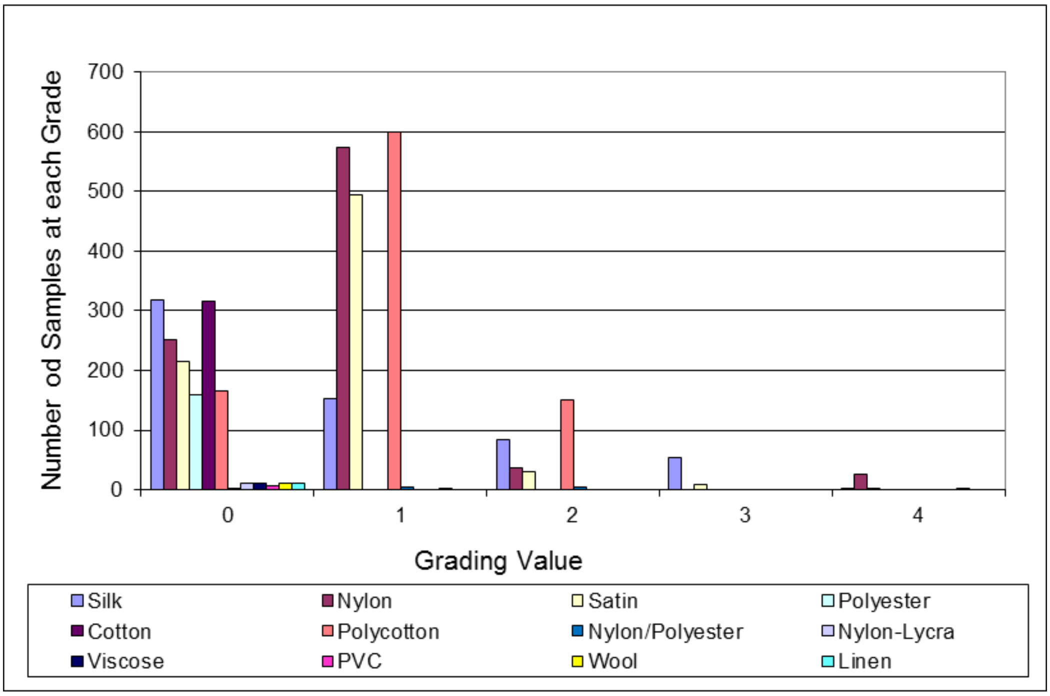


Figure 7.14: Overall number of samples with fingermarks graded from 0 (no development) to 4 (excellent) on all fabric types.

The fabrics can therefore be ranked as to the level of visualised detail (gradings 2 to 4) as follows: nylon had the most graded at 4 (26/888), no grade 3 samples and 37 grade 2 samples. This fabric also had 37 samples that were not collected, due to donors being unavailable, which may have given more samples with high gradings. Silk had only one grade 4 sample [Figure 7.15] but 53 at grade 3 and 85 grade 2. Interestingly, if it is grade 4 that is being used to rate a fabric then nylon would be first, but if it was total number of 2 – 4 ratings then it would be silk. The next best fabric was satin with two grade 4, eight grade 3 and thirty one grade 2 samples but again this fabric had samples missing (25) which might have contributed to higher grading overall. PVC only had one grade 4 sample but this fabric was only tested with one donor and at 10 days, so there were only ten samples in total therefore if more donors had been tested on PVC the ranking may be different. Polycotton had 150 samples with a 2 grading and nylon/polyester had 5 samples, but all other fabrics were equally ranked last due their 0 and 1 gradings.

Therefore, of the twelve fabrics tested, CAF visualised detail on only half of the fabrics – nylon, silk, satin, PVC, polycotton and nylon/polyester. However, the other fabrics could help with identification through targeting areas of contact for DNA. Overall it seems to be the manmade, tighter weave (nylon, satin and polycotton) and shinier (silk, satin and PVC) fabrics that allow the fingerprint residues to remain on the fabric surface and therefore allow the CA to adhere to these and form the white polymer and therefore allow the visualisation of ridge and palmar detail.

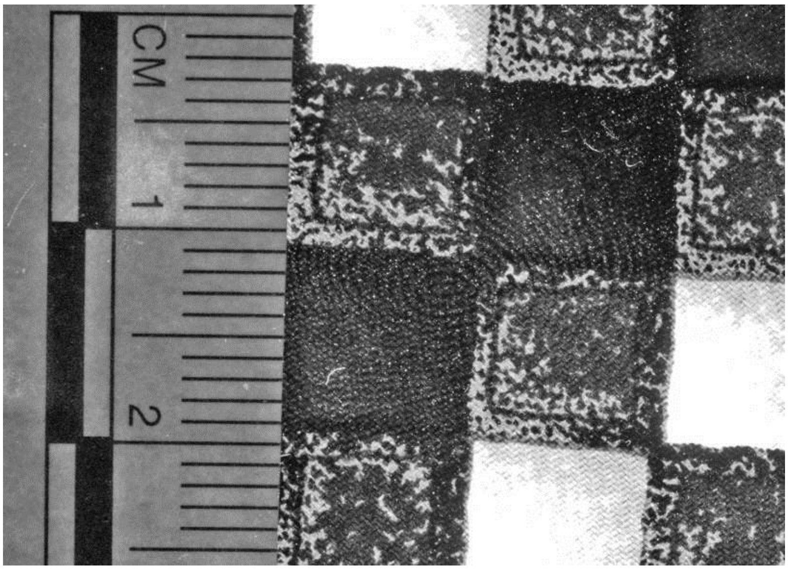


Figure 7.15: Example of a grade 4 fingermark, containing full ridge detail, on patterned silk (Al-Khairulla 2009).

7.16 Target areas visualised by CAF

Nylon/polyester produced a target area for all days except day 14; PVC for days 1, 2, 3, 4, 5 and 6; while nylon-Lycra, linen and wool did not produce any target areas. The rest of the fabrics have been included in two sets of tables and graphs that show all the target areas produced [Figure 7.16] and those showing target areas that include ridge detail [Figure 7.17]. Cotton and polycotton were the worst performing fabrics as cotton only had one day (day 3) that had 2 samples with a target area and no samples with any ridge detail and polycotton had two days (day 1 and day 21) only containing target areas and, again, none with ridge detail. Considering target areas the rest of the fabrics can be ranked (least target areas to most) as polyester, silk, satin and nylon. Polyester had days with no samples with target areas (days 4, 6 and 21) to days with 7 samples (47 %) with visualised target areas. Silk was only tested on five days (days 1, 3, 5, 7 and 21) with the number and percentage of samples with visualised target areas ranging from 26 (22 %) to 72 (60 %). Satin had a wider range of samples with visualised target areas ranging from only 3 (21 %) to 121 (91 %) and nylon was similar with 15 samples (56 %) and 24 (100 %). These target areas did not all contain ridge detail and may only be an indication that the fabric has been touched, however they could be targeted for DNA, rather than the whole article being taped.

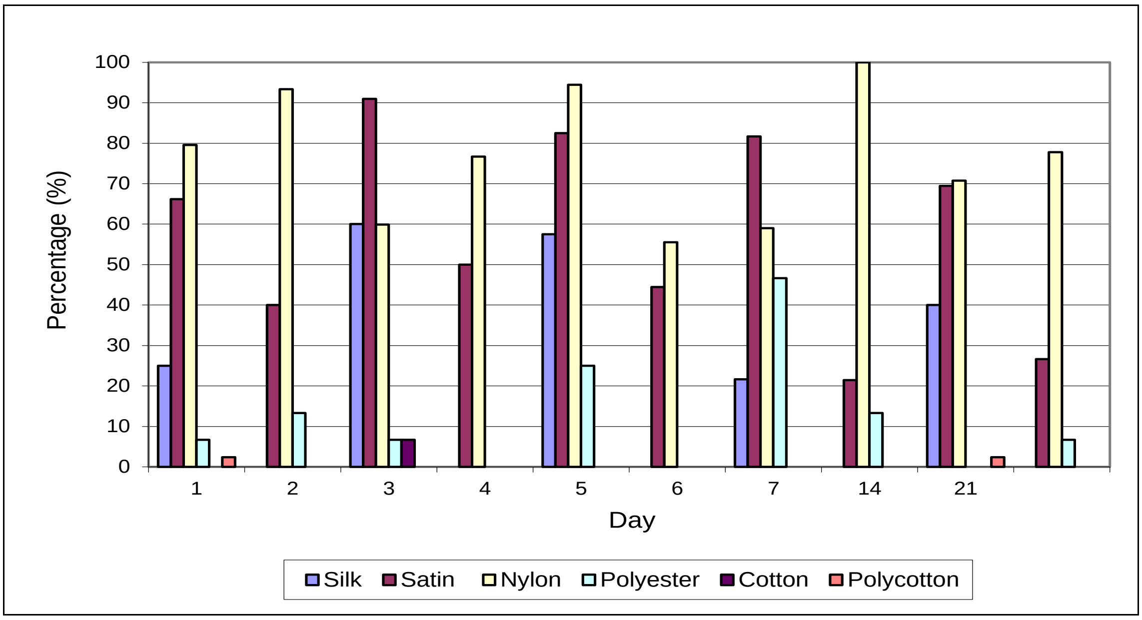


Figure 7.16: Percentage of samples with target areas visualised by CAF over the full timeline (days 1 – 7, 14, 21 and 28). Note that the fabrics with only 10 samples have not been included in the graph.

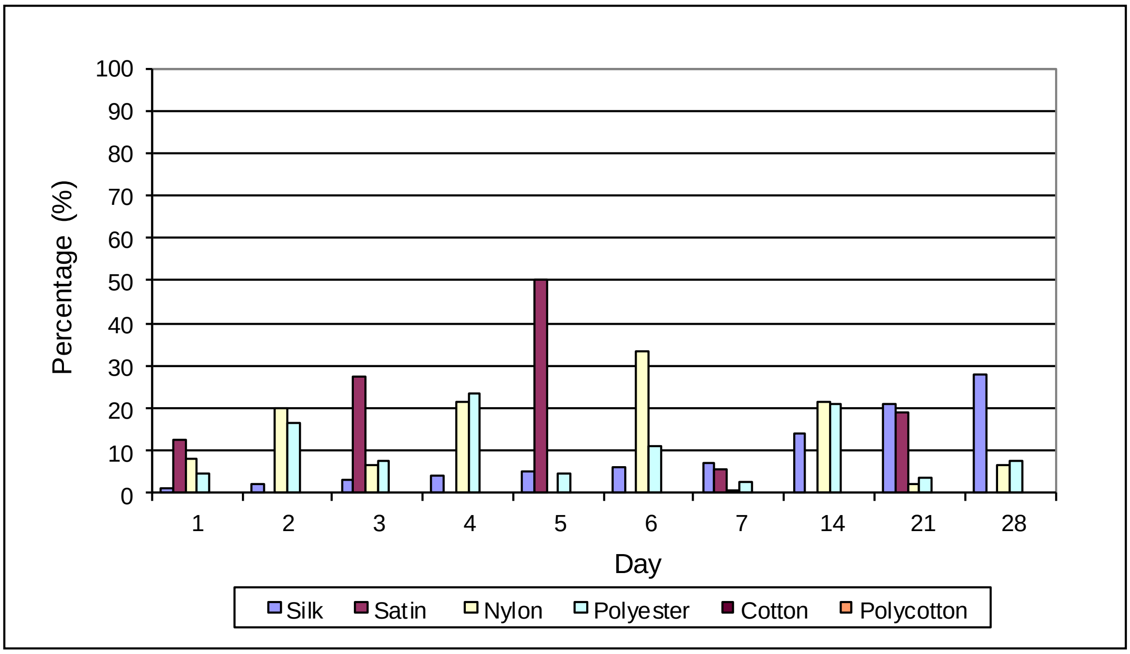


Figure 7.17: Percentage of samples with identifiable target areas, those containing ridge detail and palmar flexion creases, visualised by CAF over the full timeline (days 1 – 7, 14, 21 and 28). Note that polyester, cotton and polycotton showed no identifiable detail.

Figure 7.17 illustrates just the target areas on the fabrics that contain ridge detail, (gradings of 2 and higher) and shows that cotton, polycotton and polyester produced no ridge detail on any of the samples. Satin and nylon showed similar levels of detail though, due to nylon's day 6 samples, having more detail it was ranked higher. Even though the results are slightly skewed by the fact that silk was only tested on five of the 10 days it could be ranked highest as it produced the most samples with ridge or palm detail, with day 5 having a value of 50 %. Thus, these samples could help lead to an identification using the ridged detail from the fingers and palmar flexion creases along with any DNA that could be collected from the target areas.

7.17 Effect method of sample donation has on fingermark visualisation with CAF

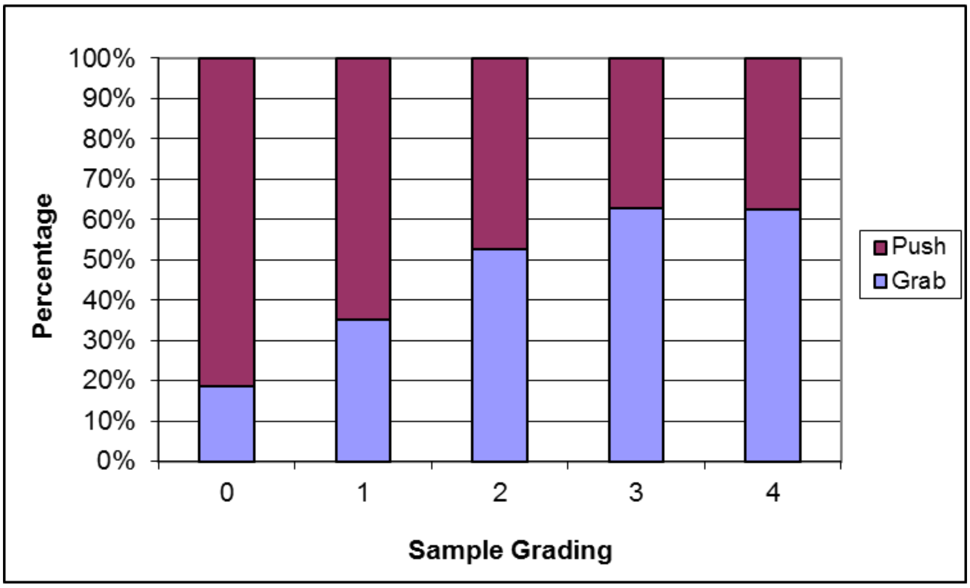


Figure 7.18: Grab versus push method of deposition on nylon fabric, showing the percentage of marks visualised with CAF. Depositions were graded 0 to 4 (1308 push samples compared to 600 grab samples).

As with VMD, the CAF study also utilised two different methods of donation to attempt to simulate the effects of an assault on fabrics. As nylon was the only fabric used by more than one researcher, this is the only fabric to be used to illustrate the differing effects of deposits (loaded and natural) and method of deposition (grab and push). However, this meant that, overall, there were over twice as many push samples (1308) as grab samples (600). Considering the results are skewed due to the differing numbers of samples between push and grabs, Figure 7.18 illustrates that the grab method leads to more ridge detail being visualised as this method has much higher percentages with gradings higher than 2. Although there were samples in the push method that had gradings of 2 to 4 there were more that were graded as 0 and 1. Therefore, if the numbers had been the same it looks as if the grab method would produce the most samples that would help lead to identification. However, the 0 and 1 gradings should not be discounted as these can help in verifying the sequences of events and lead to areas to be targeted for DNA.

A Chi-squared test was carried out to determine statistically whether there was a relationship between the deposition method (grab or push) and the grade obtained. The null hypothesis (H_0) is that there is no difference between the method of deposition (garb or push), and the alternative hypotheis (H_A) is that there is a difference between the deposition method. The p-value in this case was <0.001, which means the H_0 should be rejected and that there is a difference between the two deposition methods, therefore the H_A should be accepted.

Table 7.17: Chi-squared test results comparing the grades (0 - 4) observed for the grab and loaded technique of planting latent marks on nylon visualised with CAF. Data for the actual count obtained, the expected count, the percentage of each technique at each grade, as well as the residual value is shown.

Grade		Grab	Push	Total
0	Count	152	663	815
	Expected count	256.3	558.7	815.0
	Percentage with grade (%)	18.7	81.3	100
	Residual	-104.3	104.3	
1	Count	280	513	793
	Expected count	246.4	543.6	793.0
	Percentage with grade (%)	35.3	64.7	100
	Residual	30.6	-30.6	
2	Count	106	95	201
	Expected count	63.2	137.8	201.0
	Percentage with grade (%)	52.7	47.6	100
	Residual	42.8	-42.8	
3	Count	47	28	75
	Expected count	23.6	51.4	75.0
	Percentage with grade (%)	62.7	37.3	100
	Residual	23.4	-23.4	
4	Count	15	9	24
	Expected count	7.5	16.5	24.0
	Percentage with grade (%)	62.5	37.5	100
	Residual	7.5	-7.5	
Total	Count	600	1308	1908
	Expected count	600.0	1308.0	1908.0
	Percentage with grade (%)	31.4	68.6	100

The residual values results shown in Table 7.17 indicate that the grab method of deposition was observed less often at grade 0 than expected whilst the push method was observed more often than expected. However, the rest of the grades showed the opposite trend with all the grab deposits being observed more often than expected. Therefore, this indicates that the grab method gave more ridge detail than the push method when the method of visualisation was CAF.

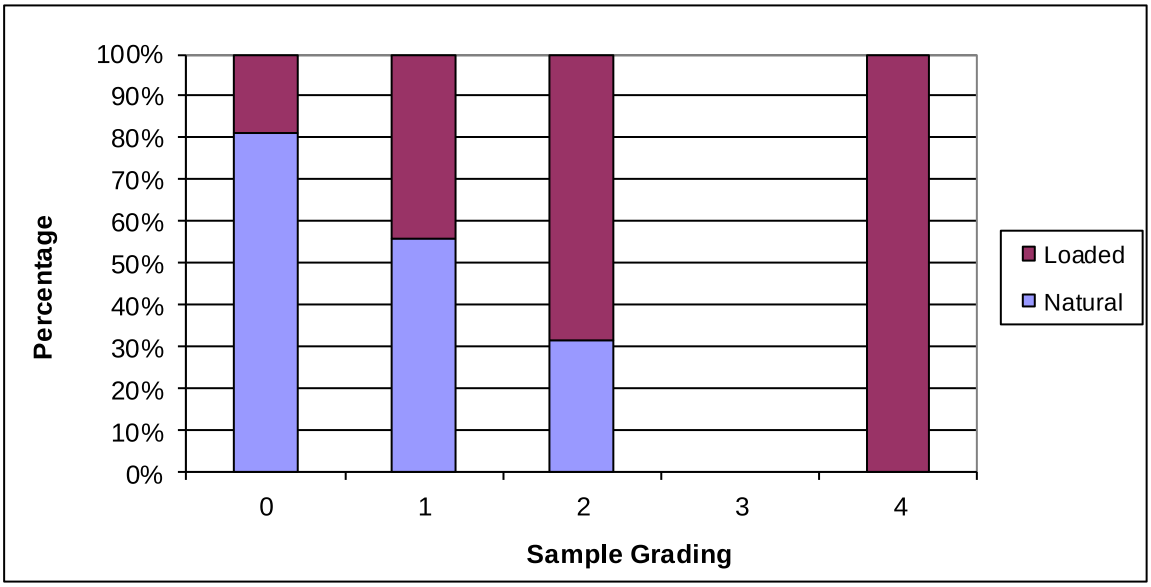


Figure 7.19: Loaded versus natural deposition on nylon fabric, showing the percentage of visualised marks graded at 0 to 4 (150 natural samples compared to 118 loaded samples, as 32 samples not collected).

To demonstrate the optimum method of fingermark deposits with CAF, the results from only two researchers who had the same number of donors and developed samples after the same number of days were used. With CAF, the results were the opposite to those of VMD with the loaded method, as more grade 2 and 4 ridge detail was observed compared to the natural method of deposition [Figure 7.19]. Natural this time did have some gradings of 2 that contained ridge detail, but the majority were 0 and 1, thus no development or only touches. This may be because the loaded marks contain more residues (amino acids, fatty acids, proteins and moisture) and therefore they allowed more polymer to adhere and therefore produce more visible white polymer ridges. Interestingly, neither the loaded nor the natural methods led to any of the samples with gradings of 3 which was unexpected as there were samples of the loaded method leading to gradings of 4. There were only 20 samples of the loaded method that led to gradings of 4, but considering there were four gradings it would be expected that you would have a mix of all the lower gradings.

A Chi-squared test was carried out to determine statistically whether there was a relationship between the treatment used (loaded or natural) and the grade obtained when visualised with CAF. The null hypothesis (H_0) is no difference between the method of deposition (loaded or natural), and the alternative hypotheis (H_A) is that there is a difference between the deposition method.

The p-value in this case was <0.001, which means the H_0 should be rejected and the H_A accepted meaning that there is a difference between the deposition methods of loaded and natural.

Table 7.18: Chi-squared test results comparing the grades (0 - 4) observed for the loaded and natural technique of planting latent marks visualised with CAF. Detailing the actual count obtained, the expected count, the percentage of each technique at each grade, as well as the residual value.

Grade		Loaded	Natural	Total
0	Count	15	65	80
	Expected count	35.2	44.8	80.0
	Percentage with grade (%)	18.8	81.3	100
	Residual	-20.2	20.2	
1	Count	59	74	133
	Expected count	58.6	74.4	133.0
	Percentage with grade (%)	44.4	55.6	100
	Residual	0.4	-0.4	
2	Count	24	11	35
	Expected count	15.4	19.6	35.0
	Percentage with grade (%)	68.6	31.4	100
	Residual	8.6	-8.6	
3	Count	0	0	0
	Expected count	0	0	0
	Percentage with grade (%)	0	0	0
	Residual	0	0	
4	Count	20	0	20
	Expected count	8.8	11.2	20.0
	Percentage with grade (%)	100	0	100
	Residual	11.2	-11.2	
Total	Count	118	150	268
	Expected count	118.0	150.0	268.0
	Percentage with grade (%)	44	56	100

From Table 7.18, the residual values indicate that the loaded samples were observed less often at grades 0, 2 and 4 than expected, whereas the natural samples were observed more often than expected. With grade 1, both the natural and loaded methods were observed less often than expected, though only by 0.4. There were no samples observed at grade 3. Therefore, the data shows that the loaded method visualises more detail on fabrics when processed using CAF.

7.18 Effect duration of CAF has on fingermark visualisation

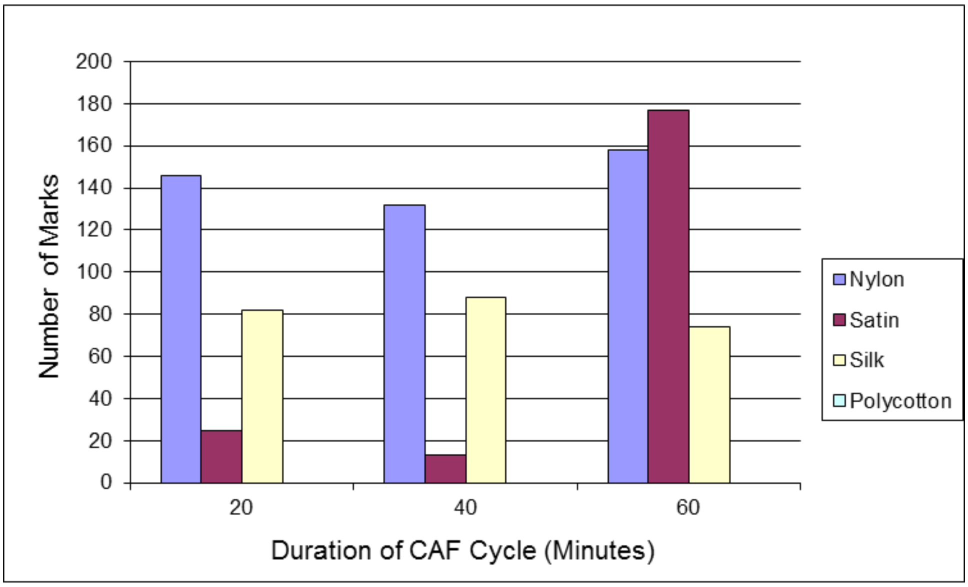


Figure 7.20:- Effect of duration of CAF cycle on the marks visualised on nylon, satin, silk and polycotton. (Only ratings of 1 and over shown - 895 in total).

Researcher 7 investigated the effect of varying the lengths of time in which the samples were in the CAF chamber during the fuming cycle and found the effects were more dramatic on some fabrics than others. With polycotton, there was no effect as there was no development at any of the fuming times. However, when looking at the samples with a grading of 1 or higher [Figure 7.20] a number of conclusions can be drawn. Silk showed little difference between each time as 20 minutes led to 82 (41 %) samples with marks, 40 minutes gave 88 samples (44 %) and 60 minutes produced 74 samples (37 %). Nylon did not have a wide variation in number of samples with marks - 146 samples (73 %) at 20 minutes, 132 (66 %) at 40 minutes and 158 (79 %) at 60 minutes, but as can be seen it did lead to more marks developing overall. Satin was the fabric that had the most variation; at 20 minutes only 25 samples (13 %) had visible marks, this dropped to 13 (7 %) at 40 minutes, but at 60 minutes this grew to an impressive 177 samples (89 %) with marks. These results appear to indicate that with satin, sample development might benefit from longer fuming times but in the majority of fabric types changing the fuming duration it does not seem to have a significant effect, therefore it may be more advisable to use shorter times and then retreat the sample.

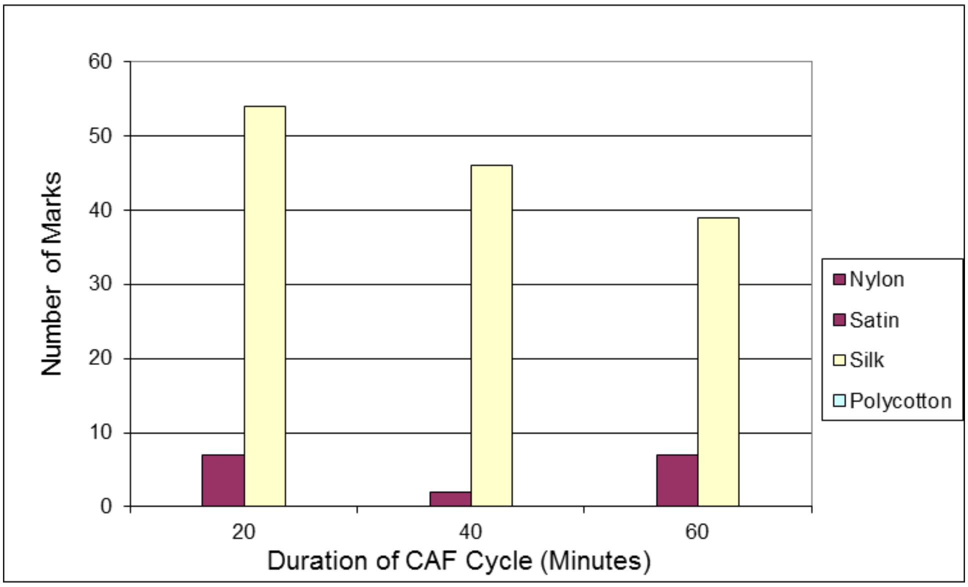


Figure 7.21: Effect of duration of CAF cycle on the number of marks developing a grading of 2 and over, on nylon, satin, silk and polycotton.

When the samples with gradings of 1 are removed from the bar chart [Figure 7.21] the results change quite dramatically – nylon disappears and satin drops to levels below 10. Silk is the only fabric to still have significant samples with gradings above 1, with 54 samples after 20 minutes, 46 for 40 minutes and 39 for 60 minutes. This indicates that as the detail drops with each 20 minutes of fuming, it is probably best to treat the sample for a short time and reprocess if it is thought improved marks will be visualised (Deacon, P. 2007. pers. comm., 15 August).

7.19 Comparison of VMD and CAF

When comparing both techniques VMD appears to give the most identifiable marks, with 99/1908 (5 %) graded as 3 or 4, compared to 91/3698 (3 %) from the CA visualisation.

Nylon, polycotton, polyester and cotton seem to be more suited to visualisation with VMD as they all had more samples graded 3 or 4 though the results are skewed due to differing numbers of samples tested with each process. It was observed that 22 % of the nylon samples were graded either 3 or 4 samples with VMD compared to only 3 % developed using CAF and no polycotton, polyester and cotton 3 or 4 graded samples with CAF. With silk, the values were a bit skewed as VMD only processed twelve samples and four were grade 4, thus 33 % of the total samples compared to CAF with 54/610 samples being grade 3 or 4, thus 9 %. With satin, there were no 3 or

4 graded samples with VMD, but 10 were visualised with CAF. Therefore silk and satin seem to be more suited to CAF. Linen does not appear to be a fabric that suits development with either VMD or CAF, and VMD is not useful on Lycra. Several of the fabrics (cotton, polyester, nylon-Lycra, viscose, wool and linen) utilised in the study did not allow the visualisation of any ridge detail; therefore CAF does not appear to be a suitable technique for these fabric types.

Target areas visualised with each technique also show that VMD led to higher numbers and percentages on cotton, polyester, and polycotton, whereas CAF only had one day on both cotton and polycotton that produced any marks, however CAF did perform better than VMD on nylon and satin.

There does not seem to be a "best time" for development of identifiable detail that is consistent for all fabrics utilising either development technique. Some fabrics, such as polyester and polycotton seem to allow visualisation of better or more detail in the first few days (days 1 and 2 using VMD led to 49 % and 18 % respectively). However, using CAF on some fabrics such as satin and nylon allowed more detail to be developed later – day 4 satin (21 %) and nylon (23 %) and day 14 satin (21 %) and nylon (21 %). This should be seen as positive since most assaults are reported to the police within a few days some individuals may take longer to report the crime. Therefore, even though identifiable marks may not be visualised a target area for DNA collection or a picture of events of the assault may be determined. This of course depends on the fabric type and the assailant's ability to leave marks that can be developed visualising ridge detail and palmar flexion creases, as poor donors seem to consistently leave poor quality ridge detail or target areas across all fabrics and development techniques.

Overall, from the results it was determined that VMD processing led to the most identifiable marks (graded 3 – 4) and more target areas being visualised than CAF. While VMD had more target areas on polycotton, polyester and cotton, CAF visualised more on nylon and satin. In addition, both techniques appear to be more successful on shiny, tight weave fabrics, such as nylon than dull rougher fabrics, such as cotton.

8. EFFECTS OF VARYING AMOUNTS OF WATER ON SAMPLES VISUALISED WITH VACUUM METAL DEPOSITION (VMD) AND CYANOACRYLATE (CAF)

8.1 Aim

To determine the effects that varying amounts of water have on the level of detail visualised by VMD and CAF on white satin, black satin, nylon, nylon-Lycra and linen and to determine the relative hydrophobicity and hydrophilicity of each of the fabrics utilised.

8.2 Introduction

Due to the nature of many crime items collected from crime scenes are not always in pristine condition and may be dirty, broken or even wet. For example, during an assault the victim may be beaten, their clothes torn and then left for dead. Therefore, the victim and their clothing will be exposed to the environmental conditions, such as sun, wind, rain and even morning dew. All the samples that have been used previously in the current work have been clean, new, unwashed fabrics, which have not been affected by contaminants or environmental conditions. The effect that different levels of water have on the detail that can be visualised with both VMD and CAF is now reported. It is not feasible to leave the samples out in the open for adventitious water, therefore a water spray was used to simulate morning dew, moderate rain and heavy rain which represented some environmental conditions to which real samples may be exposed. This in itself is not realistic as two different items may not be covered in the same amount of water even under the same wet conditions. However, a spray bottle was used to keep the amount of water applied to the fabrics constant thus keeping the variables to a minimum.

Since VMD and CAF are the main techniques studied throughout this research these were utilised to determine the effect of moisture on the fabrics. Since both techniques work on different components in fingerprint residues, water may have different effects on how the marks are visualised. For example, Yamashita and French state in the Fingerprint Source Book, "VMD was capable of developing prints on substrates exposed to water" (2011, p. 37) and that "VMD remains effective on wetted items, whereas cyanoacrylate (CA) fuming does not" (2011, p. 37). Therefore, it would be expected that VMD would visualise marks on wet fabrics more readily than CAF however, as various amounts of water were used, it could be expected that there would be different effects on the marks and what is then visualised. This may mean that under certain wet conditions CAF may be a better technique to use. It would be expected that the less water applied to the fabric and marks, the less effect this would have on the disruption to the level of detail visualised. Thus, this section will test the hypothesis that VMD will visualise more detail than CAF at each of the different wet weather conditions – morning dew, moderate rain and heavy rain.

The volume of water added was determined by reproducing the general appearance of each weather condition on a swatch of fabric, using a spray bottle. Dew had the appearance of beads of water sitting on the surface of the fabric with little or none of the water penetrating or soaking into the surface. This result was achieved with one spray from the spray bottle (approximately 1 mL). The moderate rain had beads of water with some soaking of the water into the fabric's surface and this was achieved with five sprays, one after the other from the spray bottle (approximately 5 mL). The final weather condition of heavy rain had the water completely soaking into the fabric surface and through to the underlying surface. This was achieved with 15 sprays from the spray bottle (approximately 15 mL).

It must be noted that based on previous studies with both VMD and CAF that there may be an expectation that some fabrics may not allow the visualisation of marks or there would be very few marks visualised. Thus both the controls and treated swatches/samples would not contain marks. However, some fabrics did therefore it is the difference between these and thus between the controls and treated that are discussed in this section.

8.3 VMD Study

8.3.1 <u>VMD Treatment 1 – Dew</u>

Overall effect of dew on fabrics

As can be seen from Figure 8.1, the majority of samples 123 (82 %) contained a visible mark, with only 27 (eight controls and nineteen treated samples) not showing any indication of where the fabric had been touched. There were 33 samples out of the 150 (22 %) that had some form of detail, 28 (37 %) coming from the control samples and only five (7 %) from the samples subjected to the dew. The reduced numbers show there has been some effect on the VMD process, especially when you consider that of these samples there were only three that had the same grade showing detail whereas 23 samples had a lower grade. Overall there does not seem to be as significant a difference with 38 samples changing grade between the treated and nontreated samples and 37 staying the same, but 32 of these samples were graded 1 or 0, so would not give any information about identity. The 19 grade 1 samples may of course give information about where the fabric had been touched and therefore of some use in that case.

Overall, it appears as if dew, with approximately 1 mL of water added per sample, was less detrimental to white satin as it was the most successful with identifiable ridge detail, three grade four samples (combined treated and controls). The only other fabric to have any grade three samples was nylon with only one sample. However, considering the overall grades for both fabrics nylon had more grade 2 samples with thirteen compared to four for white satin. Therefore, for samples with ridge detail, nylon could be considered more successful. The other fabrics in order of success were nylon-Lycra (nine grade 2, twelve grade 1 and nine grade 0), linen (two grade 2, twenty one grade 1 and seven grade 0) and black satin (twenty grade 1 and ten grade 0).

The lack of detail and only touches on the black satin could be explained by the fact that silver, rather than gold + zinc was used for the visualisation and the operator's lack of experience with this metal may have led to detail being lost if the samples were left in the chamber for too long or even not long enough.

When comparing the treated and control samples it can be seen that the control samples all had higher numbers of samples with grades higher than zero. In one sense this would be expected as the addition of water could lead to fingerprint residues been washed off the surface of the fabrics, however it has been documented that VMD is a process that can develop marks on substrates that have been exposed to adverse conditions (Batey et al. 1998). Thus, less reduction in detail might be expected, especially considering the small volume (1 mL) of water added over the whole surface of the sample.

Donor three appears to be the most successful in the dew treatment as s/he was the only one to achieve grade 3 samples, though this could be expected as this donor was considered in other studies to be a good donor. Donor two was the least successful in this trial with the fewest positive marks, though again when compared to other studies reported earlier this is not unexpected as they were considered to be a poor donor.

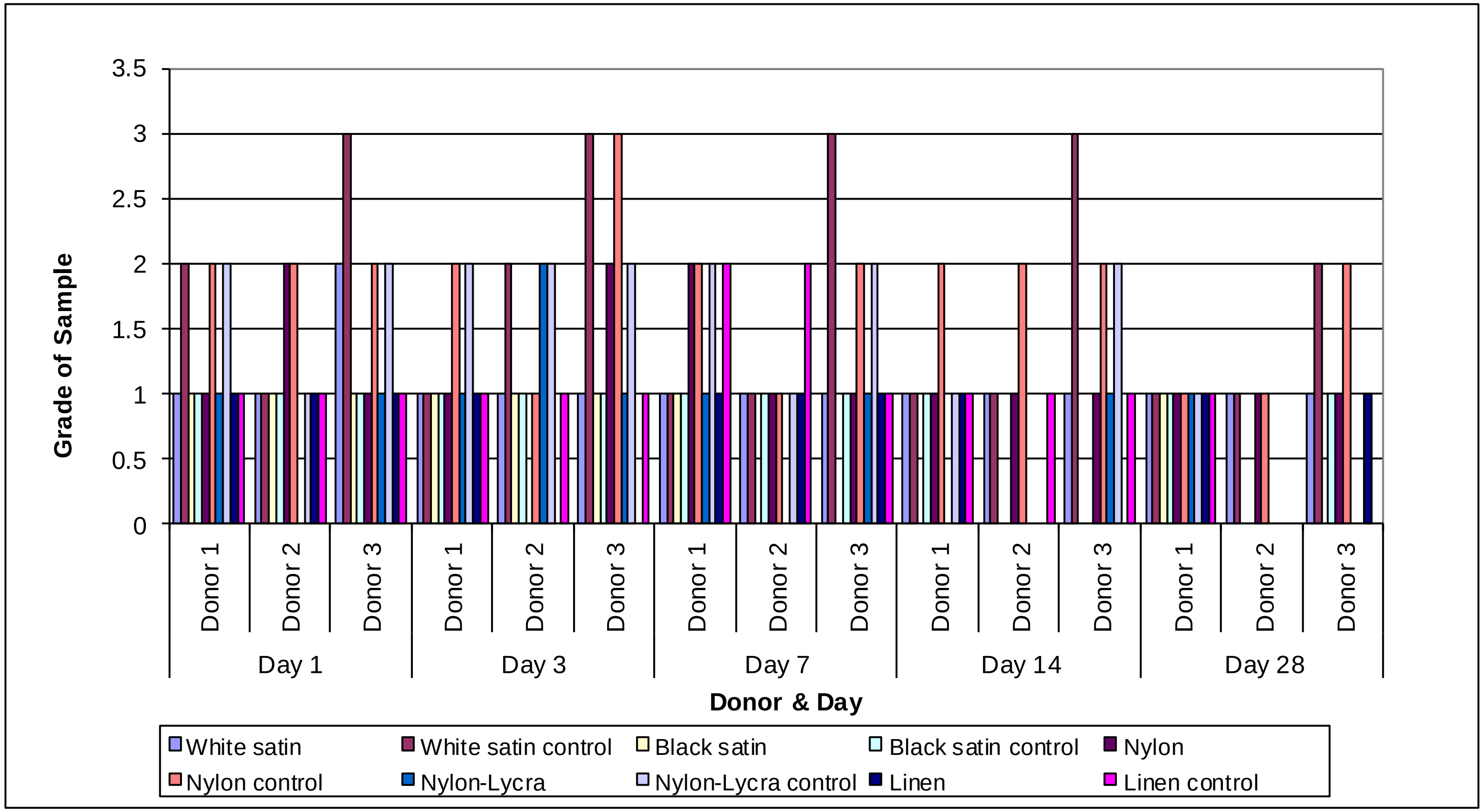


Figure 8.1: Overall results of controls and samples subjected to simulated dew on VMD processed fabrics (white satin, black satin, nylon, nylon-Lycra and linen), for a good, medium and poor donor over 1, 3, 7, 14 & 28 days.

8.3.2 Results of individual donors

Donor one

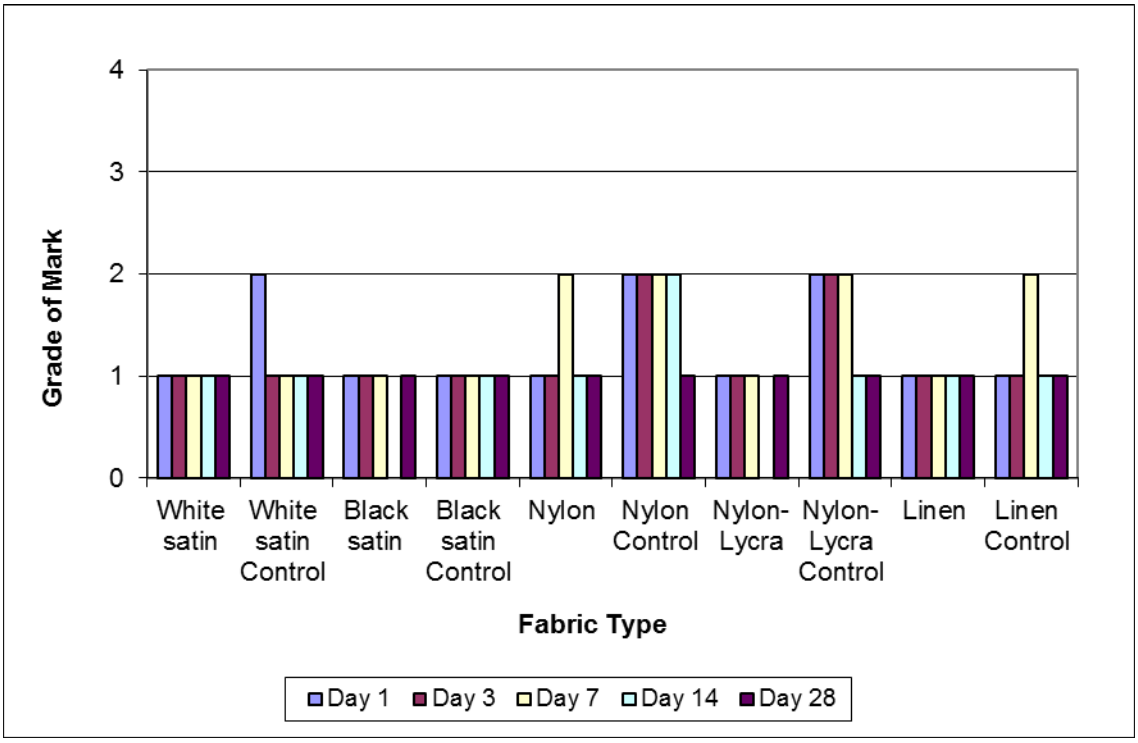


Figure 8.2: Donor one: grades of all samples and controls visualised with VMD. One half of each sample was subjected to simulated dew, while the other half acted as a control with no water added.

Donor one [Figure 8.2], who was considered to be a medium donor and would be expected at least to show some indications as to where the marks had been planted. This was the case in the majority of samples with 48/50 (96 %) being graded at one or above. The samples that were graded as zero had all been subjected to the dew, therefore even though these samples went from grade 1 on the controls to grade 0 it appears as if the water has had an effect on the marks. This donor had no samples, neither control or treated, graded at 3 or 4, therefore this reflects the medium grading this donor achieved in the other studies. There were only ten samples (20 % overall, 18 % of these from the controls and 2 % from the treated) that contained any ridge detail; therefore it is unlikely that this donor would be identified by the marks recovered from the fabrics in this study.

Examination of the results for each of the fabrics individually indicates a trend in reduction of grading from controls to treated samples. With white satin there was no change for all the samples staying at grade 1 with the exception of day one, where the control was a grade 2, whereas the treated sample was a grade 1. With black satin, all the samples were grade 1 with the exception of day 14, where the treated sample dropped to zero. There was a bigger change with nylon where days 1, 3 and 14 dropped from a grade 2 to a grade 1, with only days 7 and 28 staying the same (grade 2 and grade 1 respectively). With nylon-Lycra, only day 28 showed no effect from the moisture, while all the other days had a decrease in grading – days 1, 3 and 7 from a grade 2 to a grade 1 and day 14 from a grade 1 to a grade 0. Linen had little change at all – all samples stayed at grade 1, except day 7 which was initially graded as 2 but dropped to a grade 1 after treatment.

When considering this information there does not seem to be a correlation with age of the marks and the quality of detail observed over the timeline as the majority of the samples did not change, or had insignificant changes, in grading. Therefore, for this donor, there does not seem to be a significant decline of the detail observed over the full timeline.

Donor two

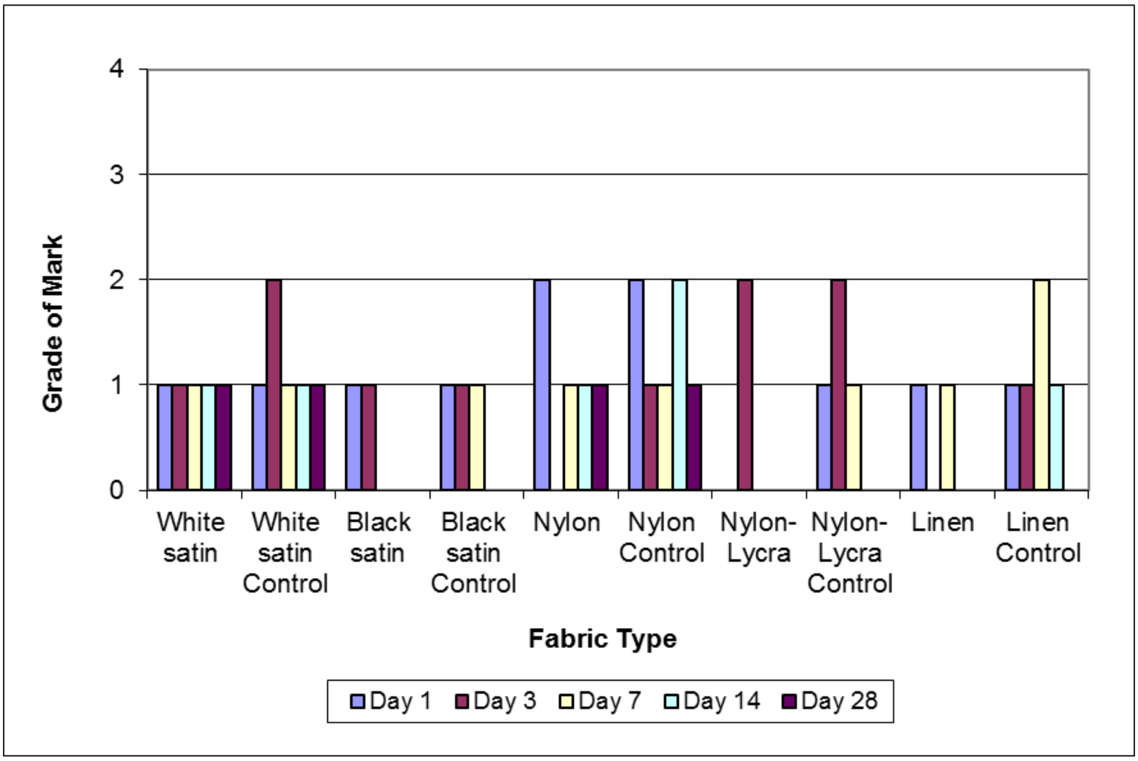


Figure 8.3: Donor two: grades of all samples and controls visualised with VMD. One half of each sample was subjected to simulated dew, while the other half acted as a control with no water added.

Donor two [Figure 8.3] is the poorest donor out of the three in this trial, and this is consistent with results from most other trials. This donor had no samples with grades higher than a 2, with 32 % being graded as zero, 54 % were grade 1 and 14 % at grade 2. These grade 2 samples only had limited ridge detail; therefore, it is highly unlikely that this donor would be identified from their marks left on fabrics.

Again, with this donor there was little change in the grades over each fabric and the timeline. White satin was graded as 1 for all days, except day 3 where it was a grade 2 on the control dropping to a grade 1 for the treated sample. Black satin remained unchanged for four out of the five days – grade 1 for days 1 and 3, grade 0 for days 14 and 28, while day 7 was the only day that changed dropping from a grade 1 to a grade 0 after addition of water. Nylon also had three days where the samples stayed the same grading – day 1 (grade 2), days 7 and 28 (grade 1), while day 3 dropped from a grade 1 to grade 0 and day 14 dropped from a grade 2 to a grade 1. Nylon-Lycra was the least successful fabric for this donor as it had the most samples graded at 0, with only one set of samples (control and treated) being rated as grade 2 and all the others were either grade 1 or 0. With linen two samples stayed the same for control and treated – day 1 (grade 1) and day 28 (grade 0), while all the others were reduced from control to treated.

There was some change in grading between the controls and treated samples – grade 0 (20 % control compared to 10 % treated); grade 1 (30 % for the control and 24 % for the treated samples) and grade 2 (10 % for the controls and 4 % for the treated samples). It cannot really be determined as to the effect of the moisture on the samples as there is not a big enough difference between the two. However, this donor is generally a poor so it would not be expected that s/he would have a great deal of ridge detail and this is what was observed.

Donor three

Donor three [Figure 8.4] could be considered the most successful out of the three in this trial as s/he was the only one to achieve grade 3 (overall 10 % of the samples) in other studies, this donor has been classed as good, so there was a presumption that they would produce ridge detail in this trial. This was the case as this donor had the highest number of positive samples – 41/50 (82 %), with 16 (32 %) producing ridge detail.

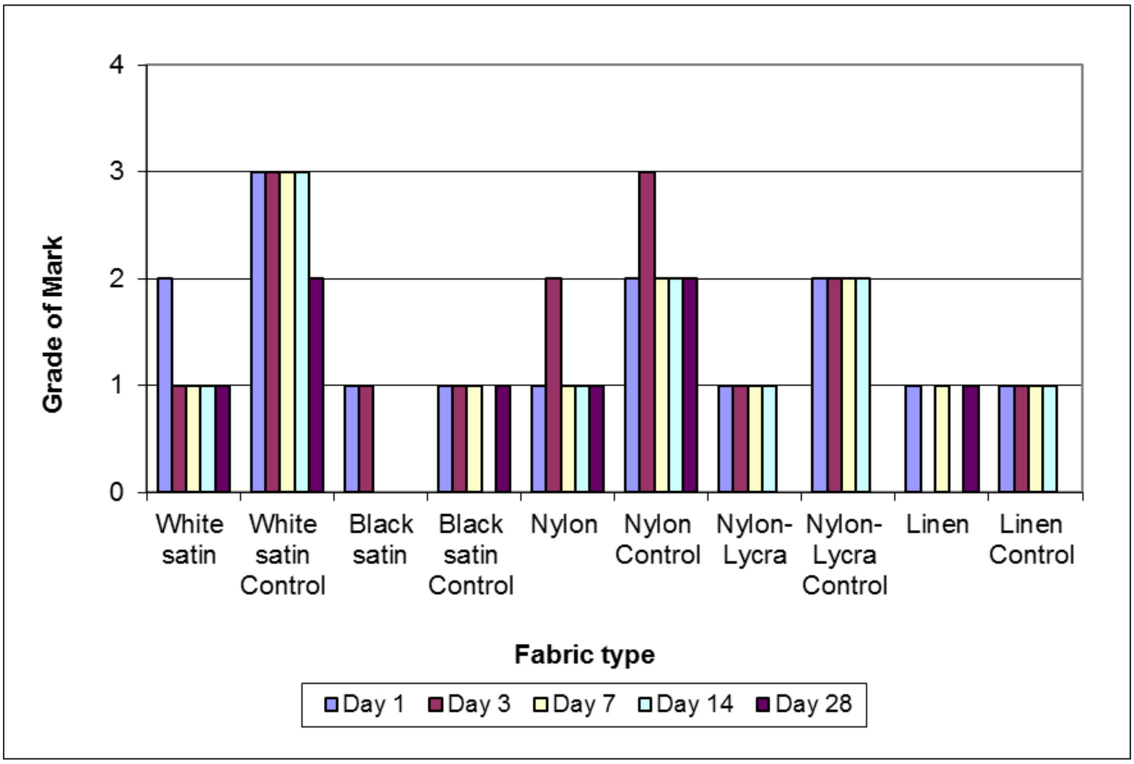


Figure 8.4: Donor three: grades of all samples and controls visualised with VMD. One half of each sample was subjected to simulated dew, while the other half acted as a control with no water added.

Looking at each fabric individually water does seem to have had a considerable effect on the samples. White satin has had a drop in grading for each day with samples showing a decrease in detail from the freshest to the oldest samples, suggesting that water has affected the detail visualised. Black satin also only had samples graded at 1 or 0 – either remaining unchanged, such as in the case of day 1, 3 (grade 1), and day 14 (grade 0), or reducing in detail, days 7 and 28 dropped from grade 1 (control) to grade 0 (treated). Nylon however does show an effect of the moisture on all the days and samples – days 1, 7, 14 and 28 were all grade 2, dropping to grade 1 for the weathered samples, while day 3 started at the higher grade 3 and dropped to grade 2. This was the same with nylon-Lycra, with all days, except for 28 (zero for both control and treated), dropping from a grade 1 to grade 0. This could have again been due to the fabrics construction and the fact that the metals did not seem to adhere well to the surface. Linen was another fabric without samples graded higher than 1 and of those two days (1 and 7) remained at grade 1 for both the control and treated sample, while days 3 and 14 dropped from a grade 1 (control) to a grade 0 (treated). Day 28 however showed an improvement rising from a grade 0 for the control to a grade 1. This could be due to several factors such as the donor not grabbing the fabric evenly thus not depositing the same amount of residues on each portion of the fabric or that they did not have an even amount of residues on their hand at the time of deposition.

Considering the controls versus the samples that had been treated with water it can be seen that there are less positive samples with detail for those that had been treated with water. There were nine (18 %) graded at 2 for the controls and only five (10 %) for those treated with water, while there were no grade 3 samples for the treated samples and five (10 %) for the controls. The only sample that was higher was day 28 linen, which was grade 0 for the control but rose to grade 1 after treatment. This difference may have been related to the rough surface of the fabric on the different sections being tested leading to different levels of detail observed.

8.3.3 VMD Treatment 2 – moderate rain

Overall effect of moderate rain on fabrics

With this treatment, the addition of 5 mL of water per sample, [Figure 8.5] 118 (78 %) of the samples were positive for marks, with the highest percentage being touches or grade 1 (51 %), followed by grade 2 at 23 %, with these samples containing some level of ridge detail. There was much less success with the higher gradings, with only 3 % at 3, and 1 % at 4. Overall, 27 % of the samples contained some level of ridge detail, which illustrates that even with the increased water added, VMD can still visualise detail, though this was dependent on the donor and the secretions they deposit as well as the surface of the fabric. The water caused an effect with the treated samples, as the detail reduced in the majority of samples that had been subjected to the moderate rain.

The only samples to increase in number were the grade 1 and grade 0, though this makes sense if water really is affecting the level of detail – the control samples that had gradings of 2 to 4 dropped down one grading, while the sample controls that were graded as 1 generally dropped to 0 or remained the same.

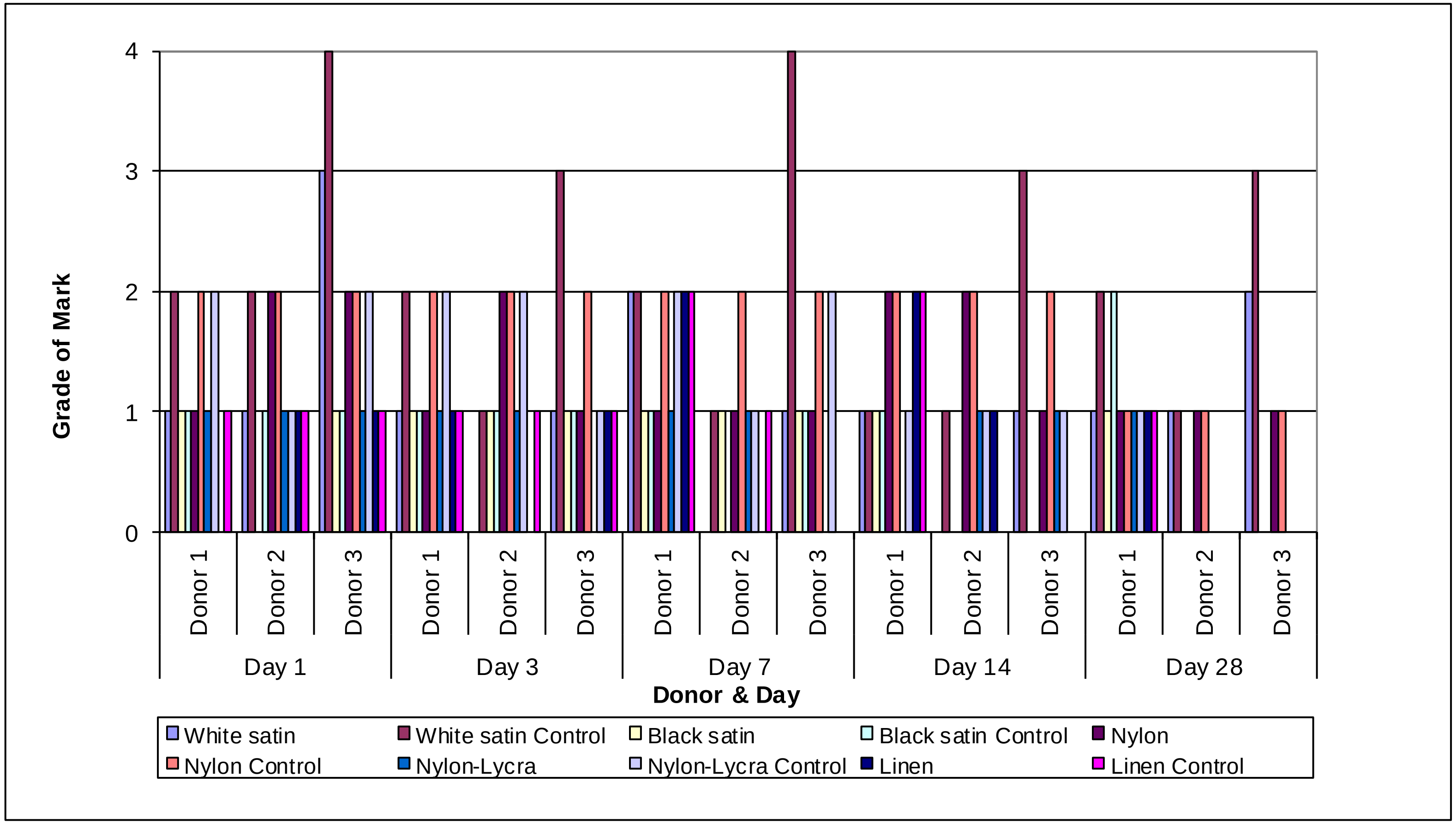


Figure 8.5: Overall results of controls and samples subjected to simulated moderate rain on VMD processed fabrics (white satin, black satin, nylon, nylon-Lycra and linen and controls), for a good, medium and poor donor over 1, 3, 7, 14 & 28 days.

With this moderate rain treatment, it was white satin that was the most successful as it was the only fabric that showed grades 4 and 3. This is most likely due to the fabric surface as it is smooth and has a tight weave and consequently considerable water just sat on the surface rather than soaking into the fabric. Thus the residues may have survived the "rain", not been washed off and thus been available for the metals during VMD. Donor three (the best donor) had highest grades and this should be expected that s/he would produce detail as well as indications of where the fabric had been touched. Donor one was next, followed by donor two and this follows the trend from previous studies also – donor one is considered a medium donor and donor two a poor donor. There was little change with the black satin – the majority of the samples remained the same, either grade 1 or 0, with the only two samples dropping in gradings being day 1 donor two (1 to 0) and day 28 donor one (2 to 1). Again, the lack of detail and the fact that really only touches could be seen was most likely due to the inexperience in the operator in the use of silver metal. Nylon had more success in retaining the same level of detail between the controls and the treated samples with eight out of the fifteen remaining the same grade (either 2 or 1), while the other seven samples dropped from a 2 to 1. Therefore, with this fabric 100 % of the samples resulted in a target. The moisture added had a definite effect on the nylon-Lycra – all of the earlier days (1 – 7) had reductions in the level of detail observed, either dropping from a grade 2 to 1 or grade 1 to 0. On the later the only sample to change grade was donor one on day 14 from a 1 to a 0. With linen there was little change between all the days and treatments with eleven of the samples remaining the same between control and treated sample. The only samples to change were day 1 donor one, day 3 donor two, day 7 donor two, all dropping from grade 1 to 0 and day 14 donor two rising from 0 to 1 in the treated sample. This increase was unexpected as the increase in amount of water would be expected to reduce the level of contact and detail, thus this could be uneven distribution of residues on the donor's hand or an uneven grab of the swatch. Overall, however there does seem to have been an effect on the level of detail and even contact observed between the controls and treatments, thus it appears that there is an effect on the VMD by the addition of water.

8.3.4 Results of individual donors

Donor one

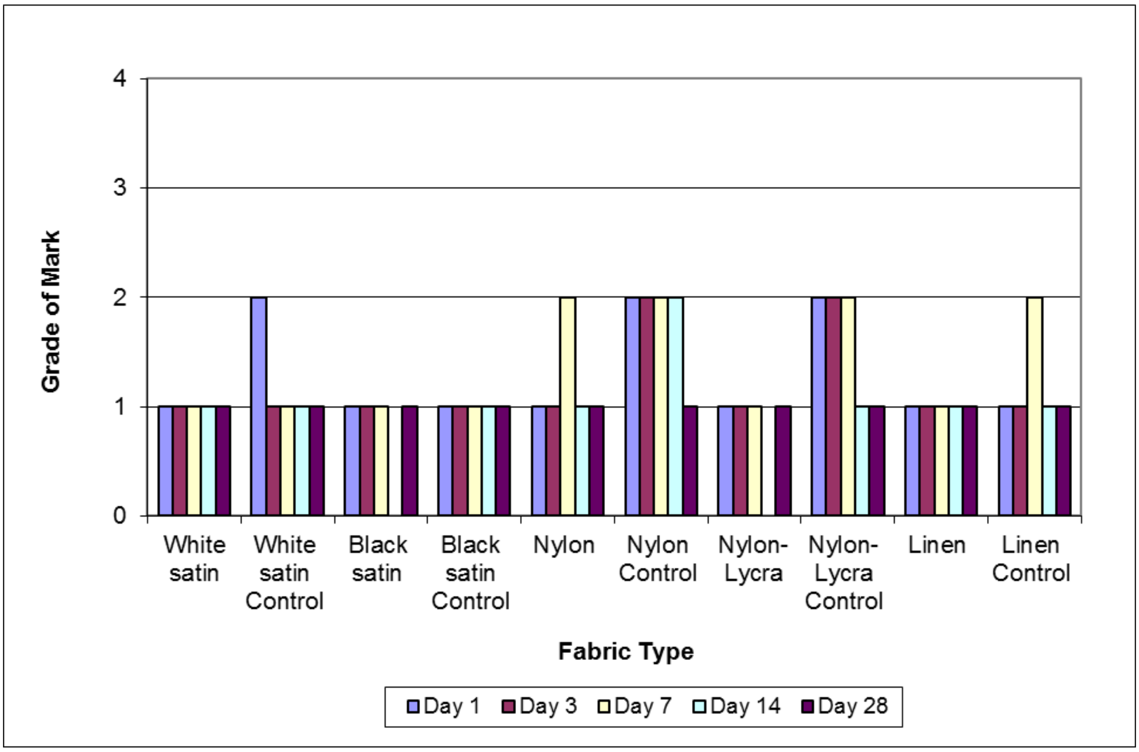


Figure 8.6: Donor one: grades of all samples and controls visualised with VMD. One half of each sample was subjected to simulated moderate rain while the other half acted as a control with no water added.

Overall, donor one [Figure 8.6] had the least number of negative samples (2; 4 %) and both were weathered samples, though they also had few samples containing ridge detail, only 10 samples (20 % in total and all grade 20). The majority of the samples (76 %) were grade 1. Nylon appears to be the most successful fabric for this donor with four of the controls being graded 2, thus containing some ridge detail and one of these samples (day 7) remained at grade 2 in the weathered half of the sample. White satin with this donor was positive for all the samples though they were all only touches (grade 1) with the exception of the day 1 control that was grade 2. Black satin again only had grade 1 touches on all the samples, except day 14 – the weathered sample was grade 0. Nylon-Lycra had some ridge detail on the control samples (days 1- 7), though this was lost in the weathered sample sides, while day 14 also had a reduction from grade 1 to 0 and day 28 remained the same. Once more, linen only contained touches and one grade 2 (day 7 control). Therefore, overall there is a reduction in detail between the controls and the weathered samples. When considering samples that contained ridge detail, the controls had nine samples (18 %)

compared to only one grade 2 (2 %) in the weathered samples, thus water must have affected the level of detail.

Donor two

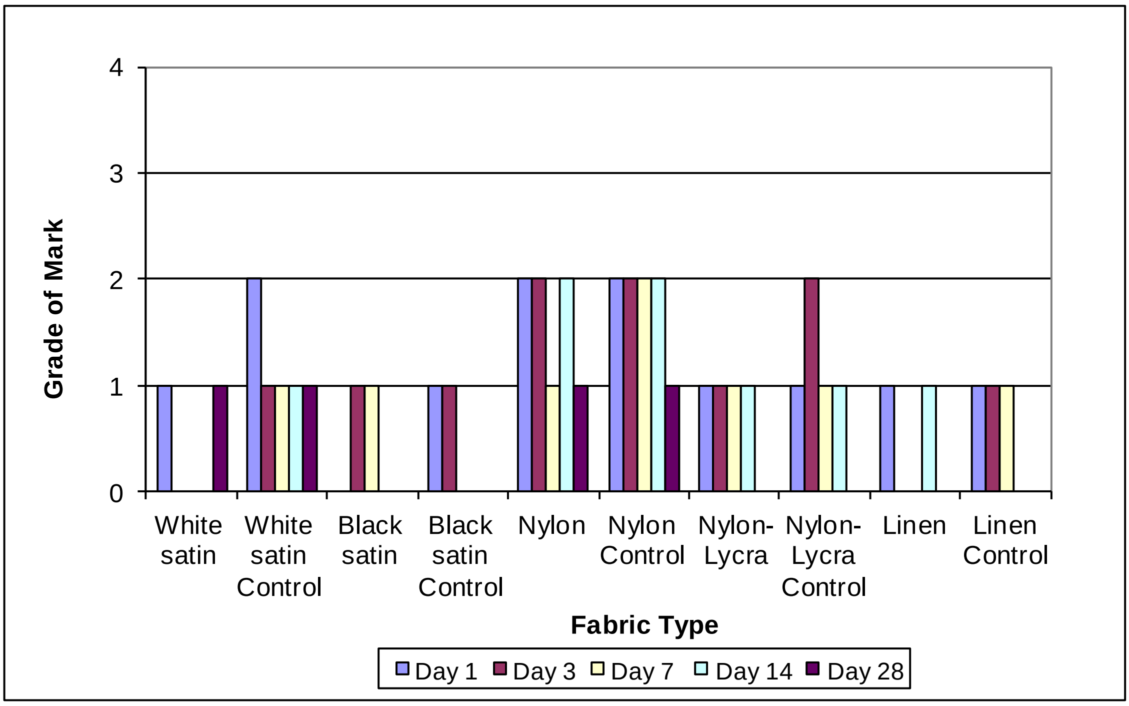


Figure 8.7: Donor two: grades of all samples and controls visualised with VMD. One half of each sample was subjected to simulated moderate rain while the other half acted as a control with no water added.

Donor two [Figure 8.7] has shown, once more, that s/he is a poor donor – they had the highest number of negative samples, 16 out of 50 (32 %) and the least number of samples with ridge detail, only 9 samples (18 %) and all grade 2. Nylon was also the most successful fabric with this donor. Days 1, 3 and 14 all graded 2 for controls and weathered, while day 7 was graded 2 for the control, dropping to grade 1 for the weathered and day 28 was grade 1 for both control and weathered; thus there seems to be little effect from the water on this fabric. White satin does however seem to have been affected by the water as all days were reduced except day 28, which remained a grade 1 for control and weathered. Black satin was the least successful fabric with this donor – days 14 and 28 were grade 0, while the other days were quite mixed. Nylon-Lycra showed a similar trend: three days (1, 7 and 14) remained the same at grade 1, while day 28 was grade 0 for both and day 3 dropping a grade from 2 for the control to 1 for the weathered. Linen had even less detail – all the positive samples were only graded at 1. Day 1 remained grade 1 for both control and weathered, day 3 and 7 dropped from grade 1 for the control to grade 0 for the weathered, day 14 had an increase from grade 0 to grade 1 for the weathered and finally day 28 was negative for both samples.

This donor's results were a bit mixed with very little detail for either control or weathered portion of the samples – only 18 % of the samples were graded above 1 and these were all grade 2. The rest of the positive samples were evenly spread between the control (26 %) and weathered samples (24 %), with a slightly smaller number of negative samples for the control samples, 12 % compared to 20 % for the weathered samples. Therefore there has been a reduction in many of the samples between control and weathered, but generally this donor has performed poorly and it is very unlikely that they would be identified from fingermarks on fabric.

Donor three

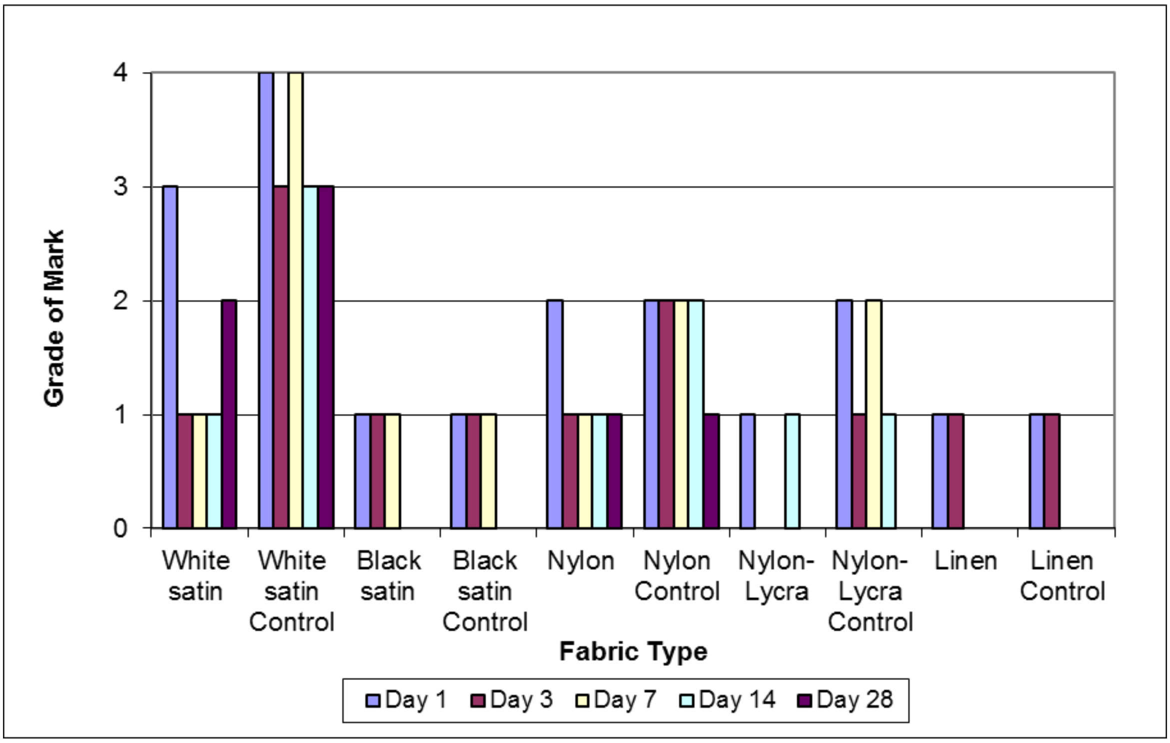


Figure 8.8: Donor three: grades of all samples and controls visualised with VMD. One half of each sample was subjected to simulated moderate rain while the other half acted as a control with no water added.

Again, donor three [Figure 8.8] demonstrates out of the donors in this trial that they are the most successful – again they are the only donor to achieve any grades higher than 2 and had the most samples with ridge detail, 14 (28 %) in total, and of these, two were grade 4 (containing excellent detail) and four were grade 3.

There does seem to have been an effect with the addition of water with all of the samples graded 2 and above since they dropped in detail from the control to the weathered samples, with the exception of nylon day 1 which remained at grade 2 for each. With white satin the change was quite significant – while days 1 and 28 only dropped one grade, days 3 and 14 dropped two grades and day 7 dropped three. Therefore, there was a dramatic loss of ridge detail in all of these samples and is most likely due to the fabric becoming completely soaked resulting in the fingerprint residues being washed away. Black satin and linen both performed poorly with only touches (grade 1) or negative samples (grade 0) for all the samples and it was the fresher samples that had positive grades – days 1, 3 and 7 for black satin and days 1 and 3 only for linen. Nylon was quite consistent with all except day 28 being graded 2 for the controls, day 28 was graded 1, while day 1 for the weathered remained a grade 2 with all the other samples being graded 1. Nylon-Lycra also had a reduction in detail for all days except day 14, which remained at grade 1, and day 28, which was negative for both control and weathered.

8.3.5 <u>VMD Treatment 3 – heavy rain</u>

Overall effect of heavy rain on fabrics

This final treatment [Figure 8.9] had the most water added, approximately 15 mL of water per sample, therefore there would be an expectation that this would have the most effect on the samples and the detail visualised. There was a reduction in positive samples with this treatment, but only seven less than for moderate rain, here there were 111 positive samples with means 74 % of all the samples had a mark indicating a touch or even ridge detail. In the case of the ridge detail there were 34 samples containing ridge detail and were graded overall at 2 to 3. The majority (29 samples) were grade 2, but there were four grade 3 samples and one grade 4 containing identifiable detail.

White satin again seems to be the most successful fabric as it is the only one that had any grade 3 and 4 samples and these were all on samples from the good donor. It also had the second fewest negative samples, only four compared to the next lowest fabric of linen at eight samples. Nylon had less negative samples, with only one of day 14 (donor two), though there was a reduction in all but three of the other samples. The three that did not reduce in grade were day 1 (donor two) and day 28 (donors one and two), but since these samples were grade 1 they did not contain any detail.

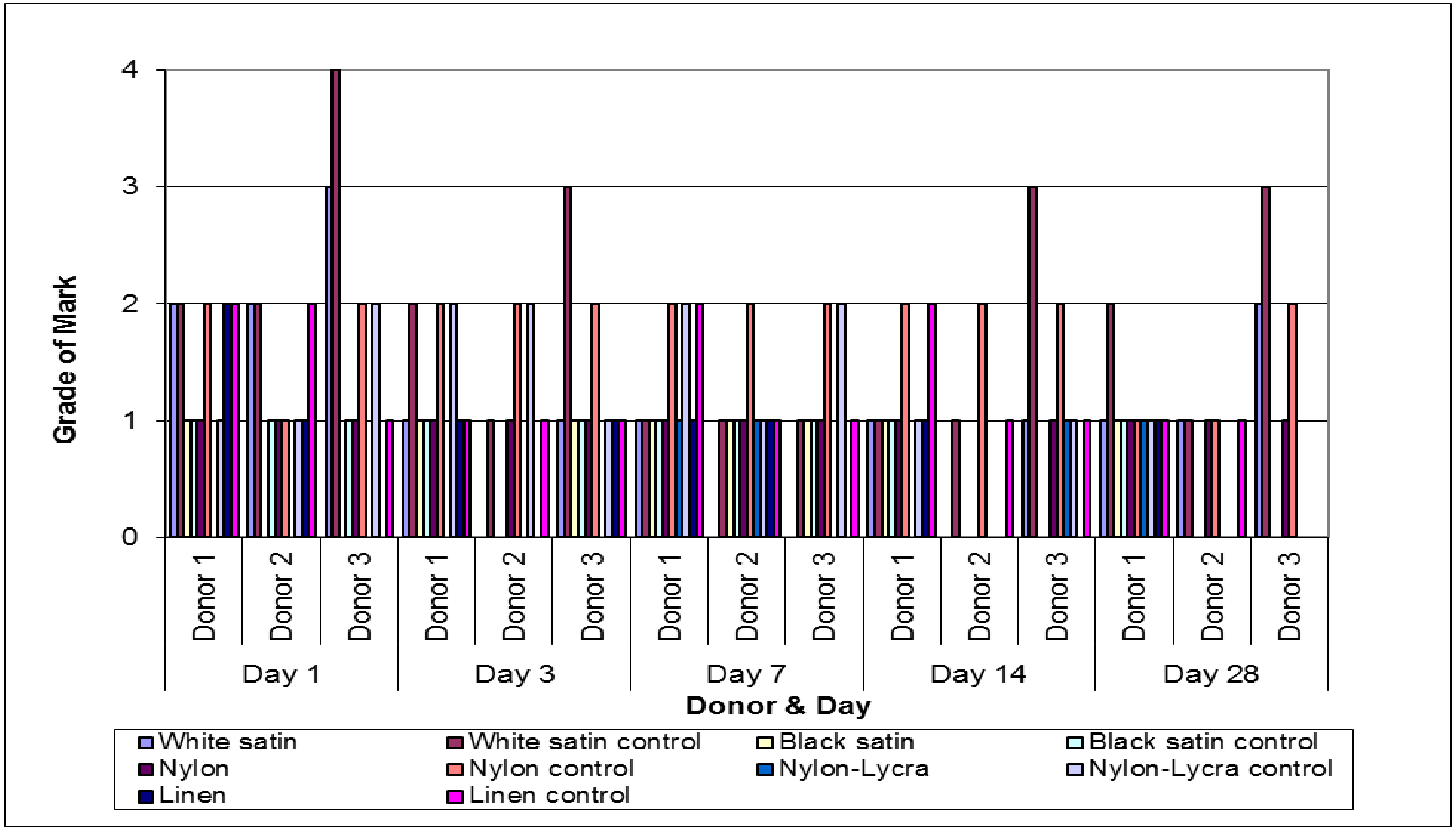


Figure 8.9: Overall results of controls and samples subjected to simulated heavy rain on VMD processed fabrics and controls for a good, medium and poor donor over 1, 3, 7, 14 & 28 days.

The other samples reduced from some detail (grade 2) to no detail and indication of a touch only (grade 1). This reduction can also be seen in the nylon-Lycra samples as the majority went from grade 2 and 1 to zero, with the exception of day 7 (donor one), which dropped from grade 2 to a grade 1 and there were also four samples that remained at grade 1. With linen there were less samples with detail to begin with; only four grade 2 samples in the controls and one in the treated samples. Therefore water has definitely caused a detrimental effect on these samples as there has been a complete loss of detail and visible marks. Finally, black satin had the least change – eight samples remained at grade 1, while five remained at grade 0. Only two samples dropped in their grade from 1 to 0. Therefore even though water did not seem to have an effect on the visualisation this fabric appears to be poor at developing marks and marks using silver VMD.

Donor one

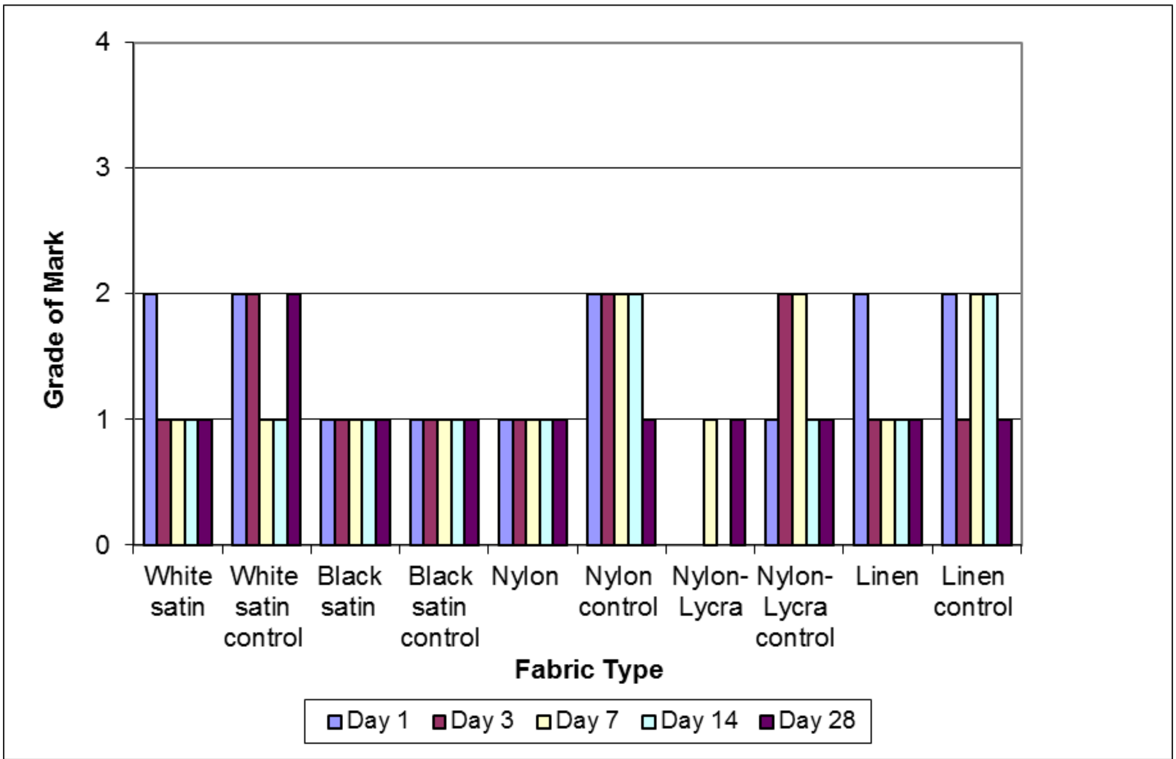


Figure 8.10: Donor one: grades of all samples and controls visualised with VMD. One half of each sample was subjected to simulated heavy rain while the other half acted as a control with no water added.

Donor one [Figure 8.10] had the most positive marks (94 %) of all the donors for this treatment. There were only 14 (28 %) of these samples containing ridge detail and these were all only at grade 2, therefore may not help with identification. Of these grade 2 samples; twelve were on the control side and only two on the treated side. White satin and linen were grade 2 in the controls and weathered samples, while all the other grade 2 samples changed to the lower grade of 1 on the treated side of the swatch.

There does not seem to be a fabric that can be stated as being the most successful. Nylon had the most grade 2 samples, but these were all on the control samples and all reduced to grade one once treated. While both white satin and linen had four grade 2 samples, three on the control side and one on the treated side. Black satin had the least detail and change – all samples were grade 1 for all the controls and treatments. Nylon-Lycra was the most changed fabric with day 28 the only one remaining at the same grade.

Due to the limited detail on the control samples it is hard to say with conviction that the water had an effect on the other half of the samples.

Donor two

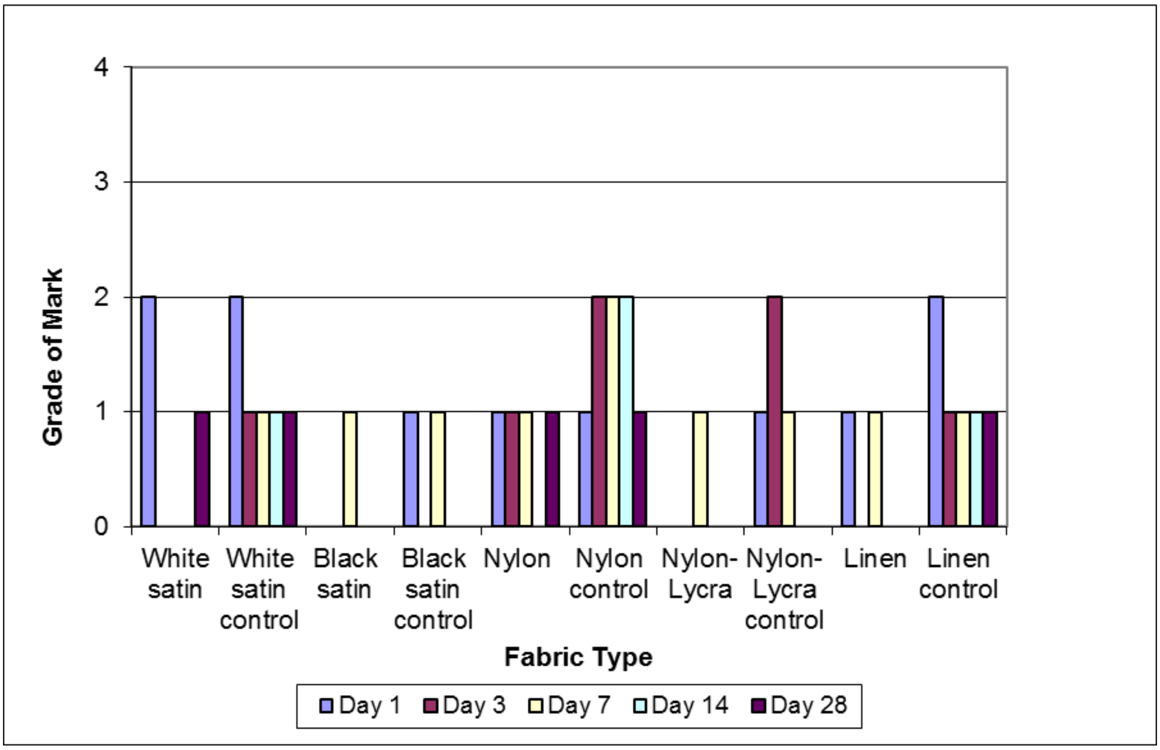


Figure 8.11: Donor two: grades of all samples and controls visualised with VMD. One half of each sample was subjected to simulated heavy rain while the other half acted as a control with no water added.

Donor two [Figure 8.11] again shows s/he is the weakest donor in this set of donors with only 30 (60 %) of their samples being positive and only 7 (14 %) of these containing ridge detail. The rest (46 %) were grade 1, therefore could only be used to give information about the circumstances or as a target area for DNA taping.

With this donor, nylon had the highest detail with three control days (3, 7 and 14) being graded at 2, however days 3 and 7 dropped to 1 and day 14 to 0 after treatment. There were only three other fabrics (white satin, nylon-Lycra and linen) that had grade 2 samples, though white satin was the only fabric where the grade 2 remained on the treated side. The grade was reduced on the treated side for both linen (down to 1) and nylon-Lycra (to 0). All the other samples were graded either 1 or 0 so they either had only an indication of a touch or were negative.

Overall, there does appear to be some indication that the water added to the samples has impacted negatively, though there was limited detail to begin with. There were only one grade 2, seven grade 1 and seven grade 0 samples that remained the same for the control and treated. All the other samples reduced in detail from 2 to 1 or 1 to 0, therefore 70 % of the samples seem to have been effected by the heavy rain. Though adverse conditions, such as rain are not expected to stop development of marks with VMD, the large volume of water, which totally soaked the fabrics either washed the marks off the surface or they were absorbed into the fabrics.

Donor three

Though this donor [Figure 8.12] did not have the highest number of positive samples, 68 % compared to donor one having 94 %, s/he was the most successful if the samples with detail are considered as this donor was the only one with grade 3 and 4 samples. There were four grade 3 samples, three on control samples and one on a treated sample and the only grade 4 observed was on a control sample. Donor one had 14 positive samples (one more than donor three), however they were all grade 2, so donor three is definitely the more successful in terms of the development of ridge detail.

White satin was the most successful fabric with this donor, being the only one to have identifiable ridge detail, with all of these samples reducing value from the control to the treated samples, showing water has affected the detail obtained. Nylon was the next best sample at allowing visualisation; all the controls were grade 2 and all reduced to grade 1 for the samples subjected to the weathering. Nylon-Lycra was the only other fabric with ridge detail, though this was only on the day 1 and day 7 control samples, but they all dropped to zero on the half subjected to water. There were only two other samples with positive grades – days 3 and 14. While day 3 dropped to a negative grade 0 for the treated half, the treated half of day 14 remained the same. Black satin and linen were quite similar in their timeline profiles. The former had five grade 1 samples, three on the control halves and two on the weathered halves, while linen had one extra grade 1 on the control of day 14.

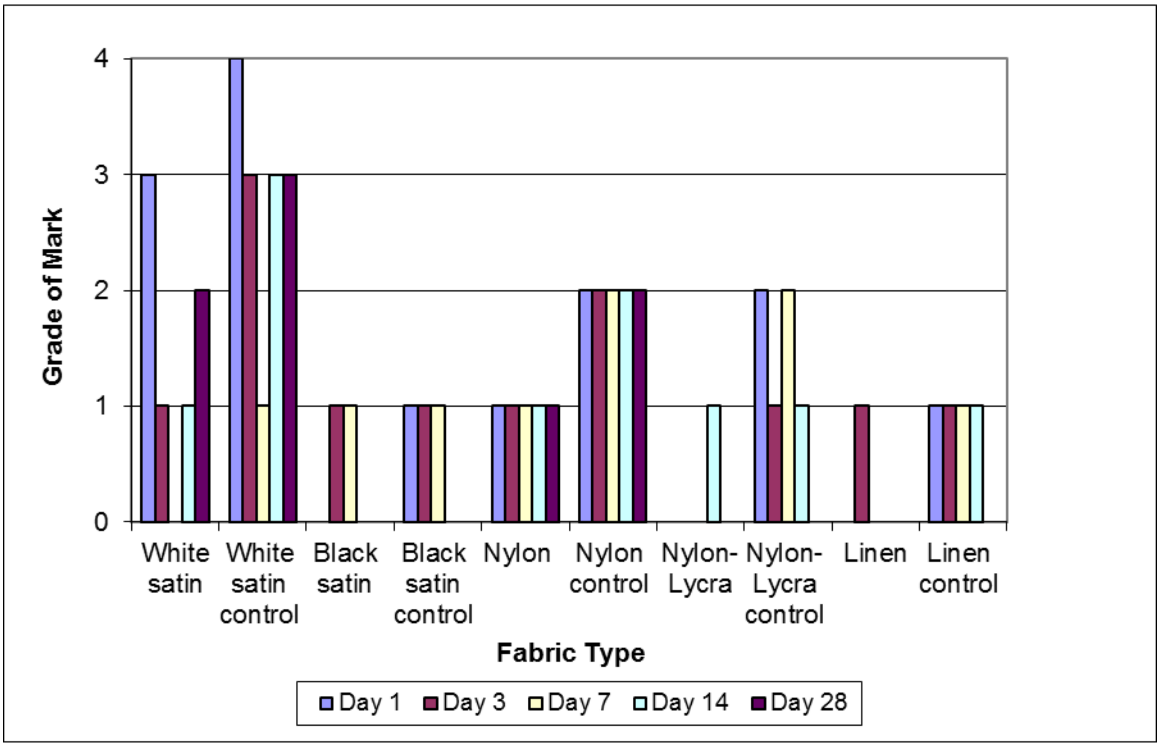


Figure 8.12: Donor three: grades of all samples and controls visualised with VMD. One half of each sample was subjected to simulated heavy rain while the other half acted as a control with no water added.

Thus, with this donor, the water affected the detail recovered from the VMD treated samples as all the samples with detail on the control samples was reduced on the sample halves subjected to the heavy rain treatment.

8.3.6 Overall conclusion

When taking all the data into consideration the effect of water can be seen by the reduction in the number of positive samples as the level of water increased. Dew was the least amount of water added and resulted in the highest number of positive marks (123/150; 82 %), moderate rain led to 118 (79 %) and, heavy rain had fewer positive samples, 111 (74 %). However, the same cannot be said of the ridge detail observed - the dew samples had the fewest samples with ridge detail (33; 22 %), moderate rain had the highest with 41 marks (27 %) and heavy rain reduced in number again to 34 marks (23 %). Rather than the expected ranking from most to least detail being dew, moderate rain and heavy rain the order appears to be moderate rain, dew then heavy rain. Therefore though the addition of water has had an impact there must also be some effect from the fabric and the donors as to the level of detail visualised with VMD.

This conclusion is based on the data observed during the study; however there were several samples including control samples that did not show any marks at all, even though they had not been affected by water. Therefore, this study needs to be repeated, possibly with artificial residues and a stamp, to determine the true effect of the water. This was not carried out originally due to a similarity in results from other studies. For example, cotton did not show much detail in previous studies, therefore there was an expectation that none would appear in this study either and this was generally the case as illustrated by the results.

8.4 CAF study

8.4.1 CAF Treatment 1 - dew

Overall effect of dew on fabrics

It can clearly be seen from Figure 8.13 that black satin is the most successful fabric in terms of visualisation with the addition of 1 mL of water in the dew section – all donors and days had positive marks (ranging from grades 1 – 3 for the treated samples), with the exception of day 7 donor three (grade 0). From other studies, donor three, had been found to be a consistently good donor, whose marks generally were obvious and, in many cases contained ridge detail. The lack of marks on this day may have been due to the increased moisture or other factors, such as cold or dry hands. The overall number of positive marks (14/15 or 93 %) for black satin may be due to the fluorescence, from the BY40 being obscured by the dark colour of the fabric. As a result, no background staining or fluorescence was observed with the Crime lites. It could also be due to the hydrophobicity of the black satin as the water tended to sit more on the surface rather than soaking into the fabric meaning that the residues were not washed off or absorbed. White satin was the only other fabric with positive marks (all grade 1) for the treatment (7 %) and 4 for the controls (27 %). It would be expected for this fabric type (tight smooth weave) that there would be more positive marks, however it was determined in water absorption tests (see section 8.6) that this fabric was more hydrophilic. Thus, it could be presumed that there were fewer residues on the fabric surface for the CAF to adhere to and therefore less visualisation.

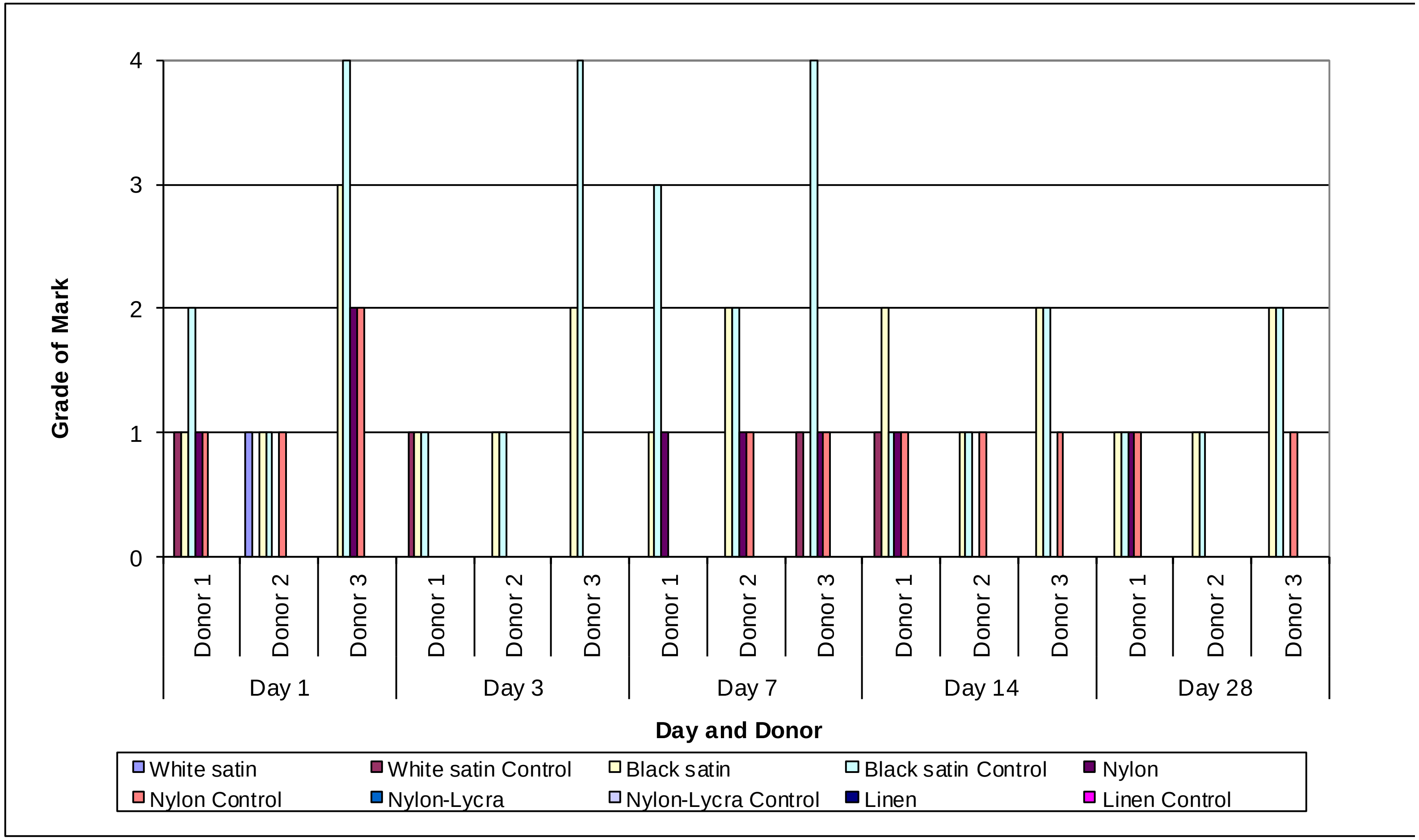


Figure 8.13: Overall results of controls and samples subjected to simulated dew on CAF processed fabrics and controls for a good, medium and poor donor over 1, 3, 7, 14 & 28 days.

With black satin there does seem to be some effect of moisture on marks that can be visualised as 40 % of the samples had decreased visualisation under the dew treatment when compared to their controls. There was no change in 53 % of the gradings and one sample (7 %) increased which reinforces the point that moisture content does affect the amount/quality of marks visualised. Nylon-Lycra and linen were negative for all donors and days (both the controls and the samples subjected to dew), which was a similar result to other CAF studies with these fabrics, so not unexpected.

A natural method of deposition was used rather than artificial residues and a stamp, because the research attempted to keep the methodology as close to a real-life situation as possible. Consequently, the lack of marks may be, in part, due to a lack of residues present on the samples. However, the donors used in this study were a mix of a poor, medium and good donor so there would be an expectation that the good and even medium donor would deposit marks. As suggested in section 8.3.6 this work should be repeated to help determine whether it is an initial lack of residues or the process (in this case CAF) that did not allow for the visualisation of marks. At the time of the study, time constraints and previously acquired data from other studies there was an expectation that CAF would not visualise much detail, therefore the same might be expected during this study. Thus, when little and in some cases no detail was observed it was not seen as unusual or unexpected, therefore the study was not repeated.

Donor one

Figure 8.14 shows the result for donor one, who from previous studies was considered a medium donor. Here it can be seen that neither linen nor nylon-Lycra had any marks visualised. In the case of linen this was not unexpected due to the open weave and roughness of the fabric previously shown to be detrimental to CAF attachment but nylon-Lycra had mixed results in previous studies. It does have a smoother surface and tighter weave, but tended not to show many areas of contact, and it has a tendency to absorb liquid, which, in turn, could dilute or remove the residues thus reducing the possibility of CAF attachment. White satin in this study had no contact marks for the treated samples with visible marks of only grade 1 for the controls, with the exception of day 7, which remained grade 0. All of the nylon samples remained the same on the treated and the controls, with the exception of day 7 where the control was grade 1 and the treated sample reduced to a grade 0. Black satin was the fabric that performed the best with this donor. One sample did go down in its grading (day 14 went from a 2 to a 1) and days 3 and 28 remained the same (grade 1), however days 1 and 7 improved by going from a grade 1 to 2 and 3 respectively. When considering the fabric weave, including tightness and smoothness, these results could be expected leading to the fabric ranking of black satin, nylon, white satin, nylon-Lycra and linen. The satins and nylon are all quite smooth with tight weaves thus marks and detail would be expected to be visualised, whereas the nylon-Lycra is not as smooth and the linen is quite rough, therefore less detail or marks would be expected.

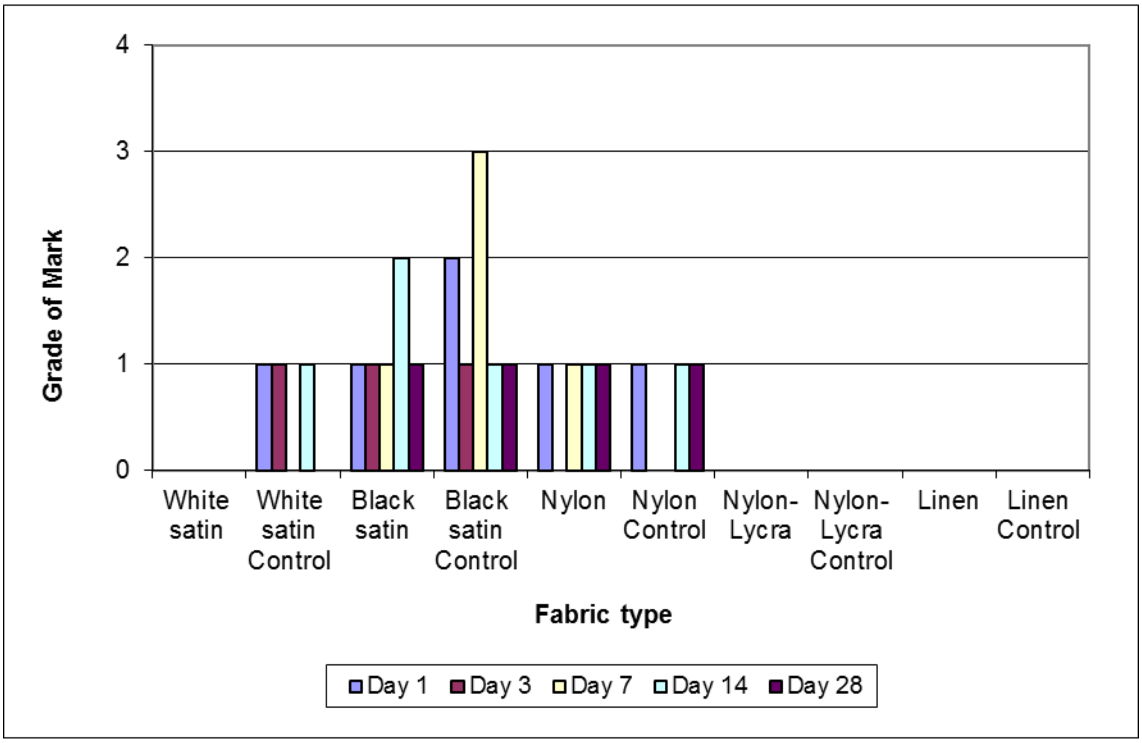


Figure 8.14: Donor one: grades of all samples and controls visualised with CAF. One half of each sample was subjected to simulated dew while the other half acted as a control with no water added.

When considering the timeline and age of the samples there does not seem to be a correlation between how old the samples are and the quality of marks visualised. Of the samples with marks, the fresher samples (days 1 and 3) did in some cases visualise touch marks (grade 1) for the treatments and controls, but it was day 7 that gave the highest grading of a 3. There was also a grade 2 for a day 1 black satin control (decreasing to a grade 1 when treated) and day 14 black satin treatment (an increase from a grade 1 on the control). Therefore if the hypothesis was that as the samples aged the grading reduced this has not been proven in these samples.

Donor two

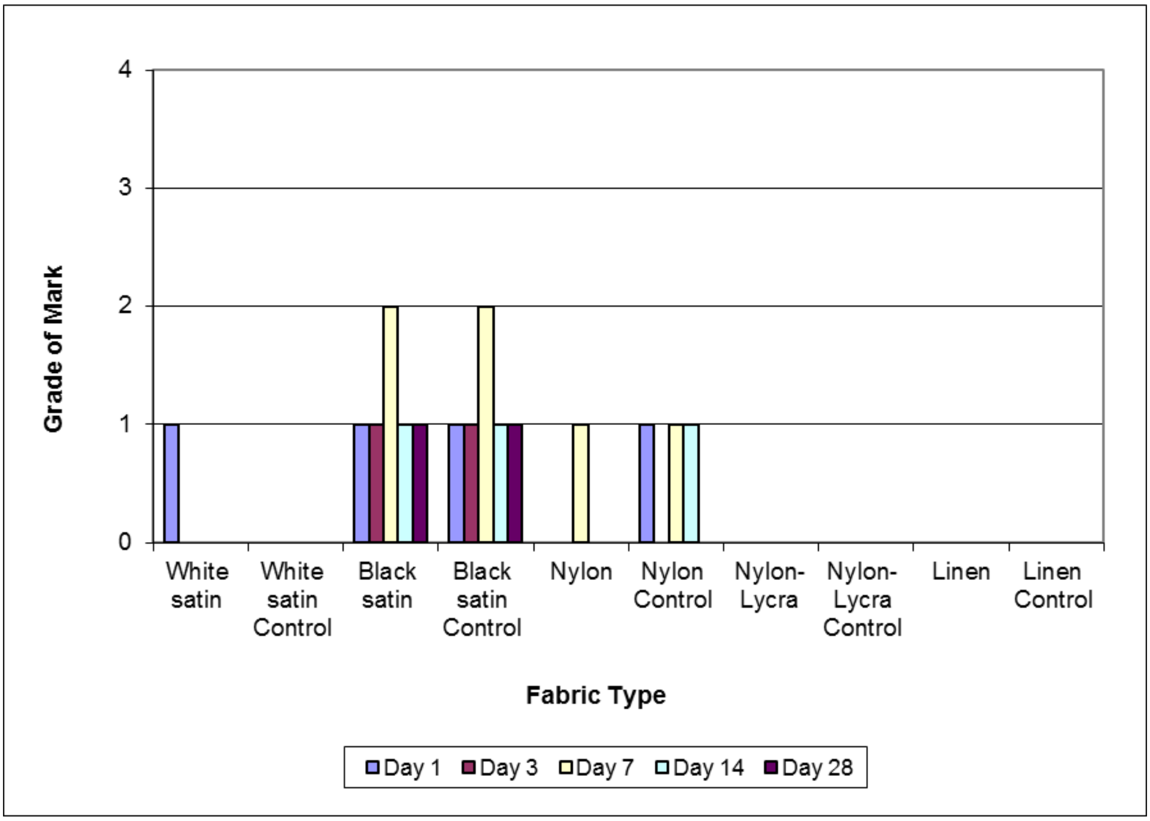


Figure 8.15: Donor two: grades of all samples and controls visualised with CAF. One half of each sample was subjected to simulated dew while the other half acted as a control with no water added.

Donor two [Figure 8.15] was the poorest of the three donors in this study as three of the fabrics, linen, nylon and all, but one, control sample (day 1) for the white satin gave no visible marks of any kind. The black satin, which was the best performing fabric with donor one, visualised marks on all days, however there was no difference between the treated and the controls. Nylon again had samples with no change between the treatment and controls on days 3, 28 (grade 0) and 7 (grade 1), however there were two samples where the grade decreased from the control to treated – from a grade 1 to a grade 0. Thus the addition of water had a small effect on the nylon samples but no change on the black satin where the grades remained the same.

Considering the age of the samples with marks, it would be expected that the fresher planted marks would be more easily visualised and extra detail would be seen, however, considering Figure 8.15, it was the older marks such as day 7 that have the highest grade (black satin – treatment and control). Overall donor two does not have many visualised marks (only 30 % of the samples) and all of them are on the high performing fabrics satin and nylon.

The addition of water did not seem to have an effect on the black satin – the gradings remained the same with the controls and those treated with dew. There does however seem to be an effect with nylon where only the day 7 of the positive control samples displayed a mark after water was added. Interestingly, with the white satin, there was only one positive sample (day 1) and this was for the dew treated sample, though this was just a touch mark, so may not have been from the grab but rather an artefact of the processing.

Donor three

Donor three [Figure 8.16] gave the marks with most detail – the only donor to achieve grade 4 marks (days 1, 3 and 7 on black satin), however these all reduced upon the addition of dew. The moisture appeared to have an effect on nylon but many of the samples remained the same with the controls and treated samples having the same grade. However days 14 and 28 went from grade 1 to grade 0 for both days, therefore it would appear that the moisture has negatively impacted on the ability of CAF to visualise marks.

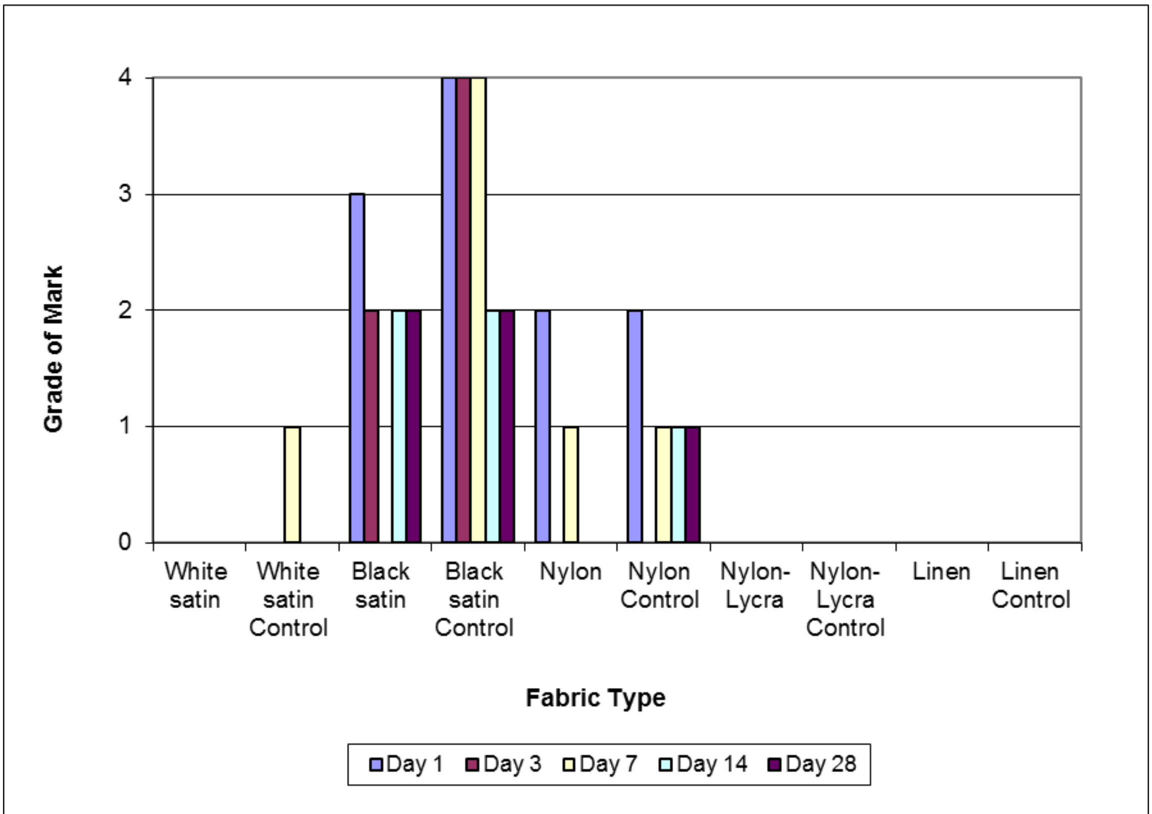


Figure 8.16: Donor three: grades of all samples and controls visualised with CAF. One half of each sample was subjected to simulated dew while the other half acted as a control with no water added.

Generally, more detail can be seen after visualisation if the fabric is hydrophobic and allows moisture to remain on the surface. Nylon and satin are more hydrophobic, therefore, there is greater visualisation, whereas linen and, unexpectedly, nylon-Lycra are more hydrophilic and allow the water to be absorbed along with the residues resulting in removal of marks from the fabric's surface leaving nothing for the CAF to adhere to and visualise marks.

8.4.2 CAF Treatment 2 – moderate rain

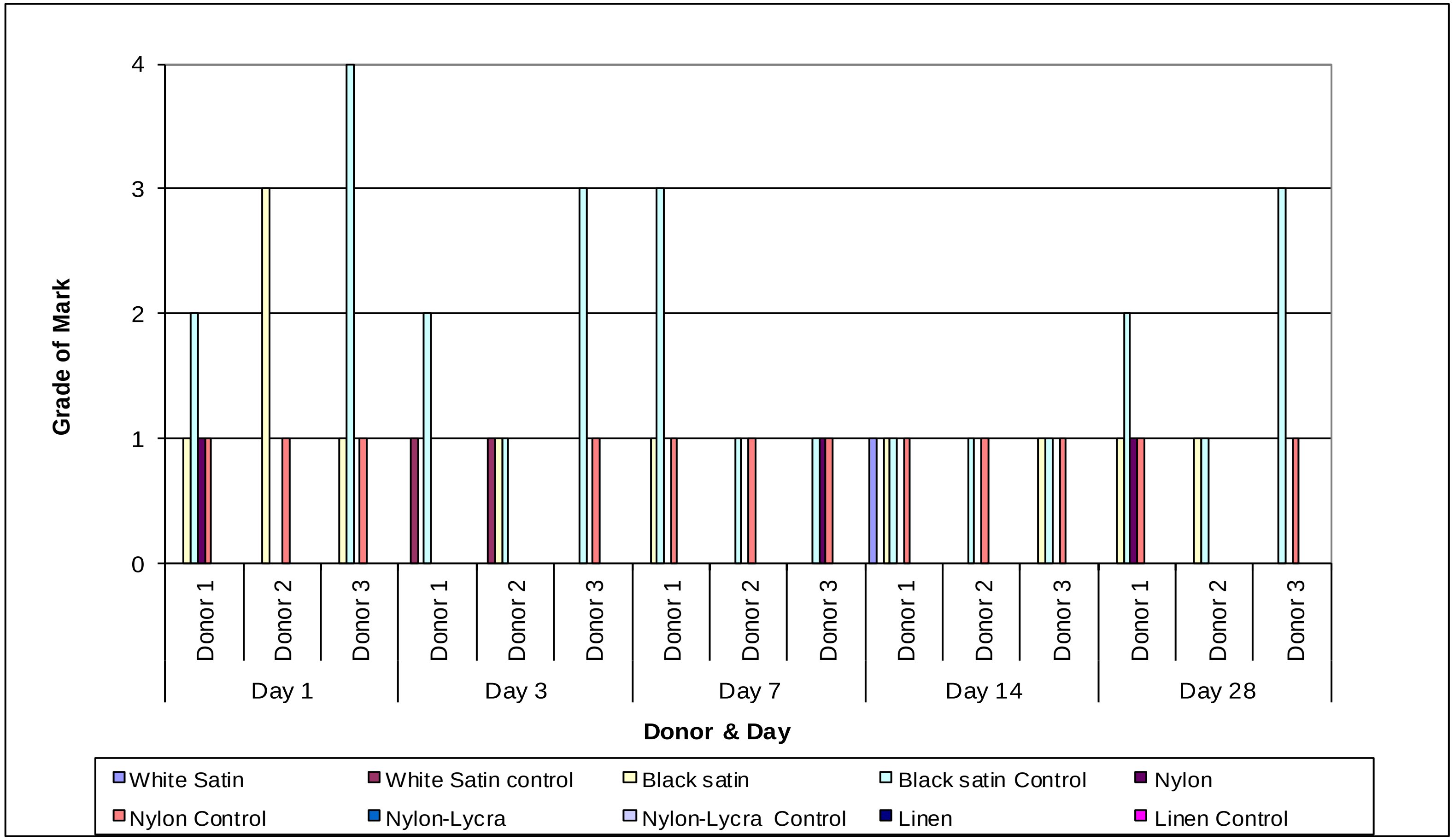


Figure 8.17: Overall results of controls and samples subjected to simulated moderate rain on CAF processed fabrics and controls for a good, medium and poor donor over 1, 3, 7, 14 & 28 days.

Overall effect of moderate rain on fabrics

When comparing moderate rain (approximately 5 mL of water) [Figure 8.17] to those of the dew treatments (1 mL of water) [Figure 8.13] there were less high grades thus it would appear that increased moisture has had an effect. However the controls where no moisture was added are also lower in grade, so CAF seems to be less able to visualise marks on fabrics. Dew had three grade 4 samples compared to moderate rain with only one grade 4. It does however have more grade 3 samples, three compared to only one in the dew. There is a definite effect with the moisture with all the higher marks lowering in grade in the treated samples. In total there were 40 samples with positive marks, 12 on the treated samples and 28 on the controls.

Donor one

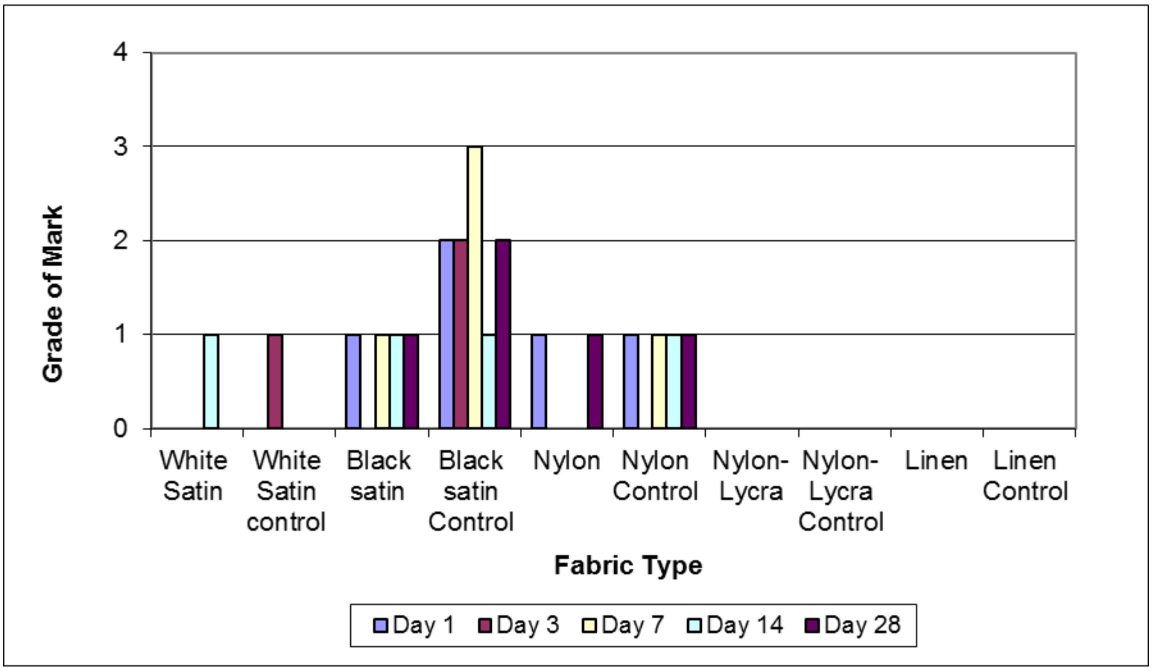


Figure 8.18: Donor one: grades of all samples and controls visualised with CAF. One half of each sample was subjected to simulated dew while the other half acted as a control with no water added.

Once more black satin [Figure 8.18] is the most successful fabric and is the only fabric to produce a grade higher than 1 with one grade 3 after treatment and three grade 2, three grade 3 and one grade 4 for the controls. All other fabrics were either grade 1 or 0 for both treatment and controls. This reinforces the view that the tighter smoother weave allows more visualisation.

Donor one, from other studies, was considered a medium to good donor, however with moderate rain s/he only performed slightly better than donor two who was considered a poor donor. For donor one – nylon-Lycra and linen were all grade 0; white satin had a grade 1 for both the treatment (day 14) and control (day 3). The nylon samples had three days with unchanged grades, days 1 and 2 (grade 2), day 3 (grade 0), whereas days 7 and 14 were zero for the treatment and 1 for the control. Black satin was once again the best fabric but all days had poorer grades for all the weathered sample.

Donor two

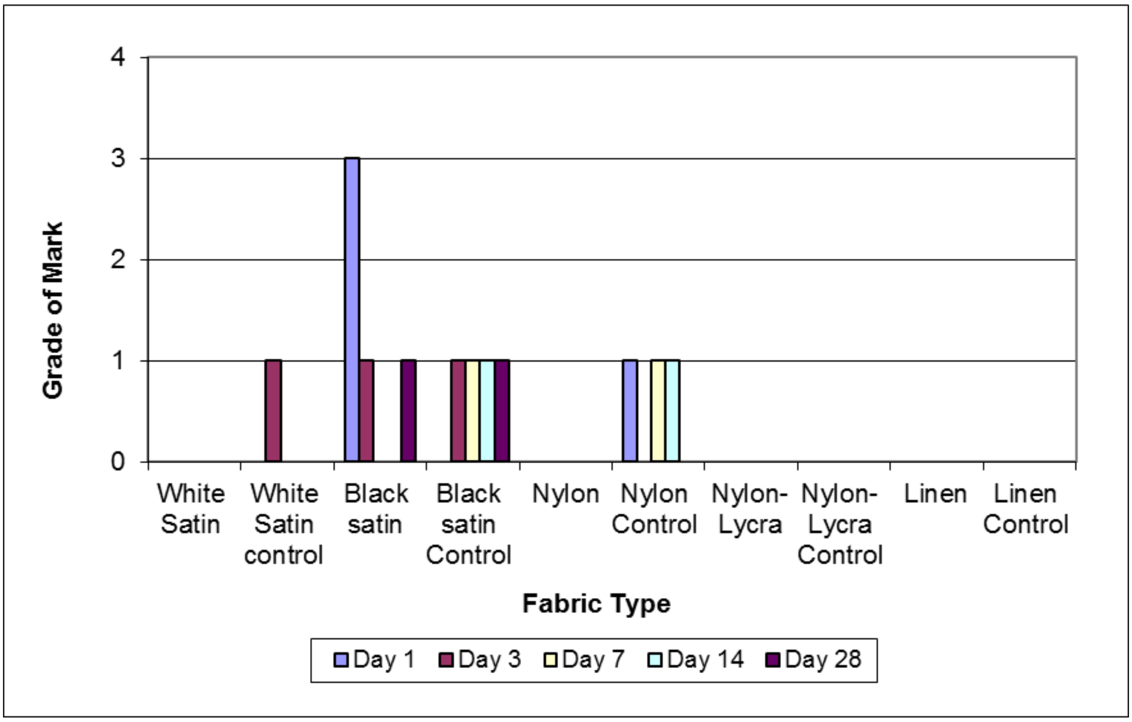


Figure 8.19: Donor two: grades of all samples and controls visualised with CAF. One half of each sample was subjected to simulated dew while the other half acted as a control with no water added.

Donor two [Figure 8.19] was once again the least successful donor having both nylon-Lycra and linen negative for all days and treatments, while white satin was negative for both treatment and controls for all days with the exception of day 3 control. Nylon only had grade 1 for the controls on days 1, 7 and 14 and black satin was negative for day 1 control as well as days 7 and 14 of the treated. Though, interestingly, black satin had grade 0 for the day 1 control, but a grade 3 for the treated, and this may be due to how the donor gripped this sample, differences in the surface of this fabric, the distribution of residues on the hand or even how the CA adhered to the residues.

Donor three

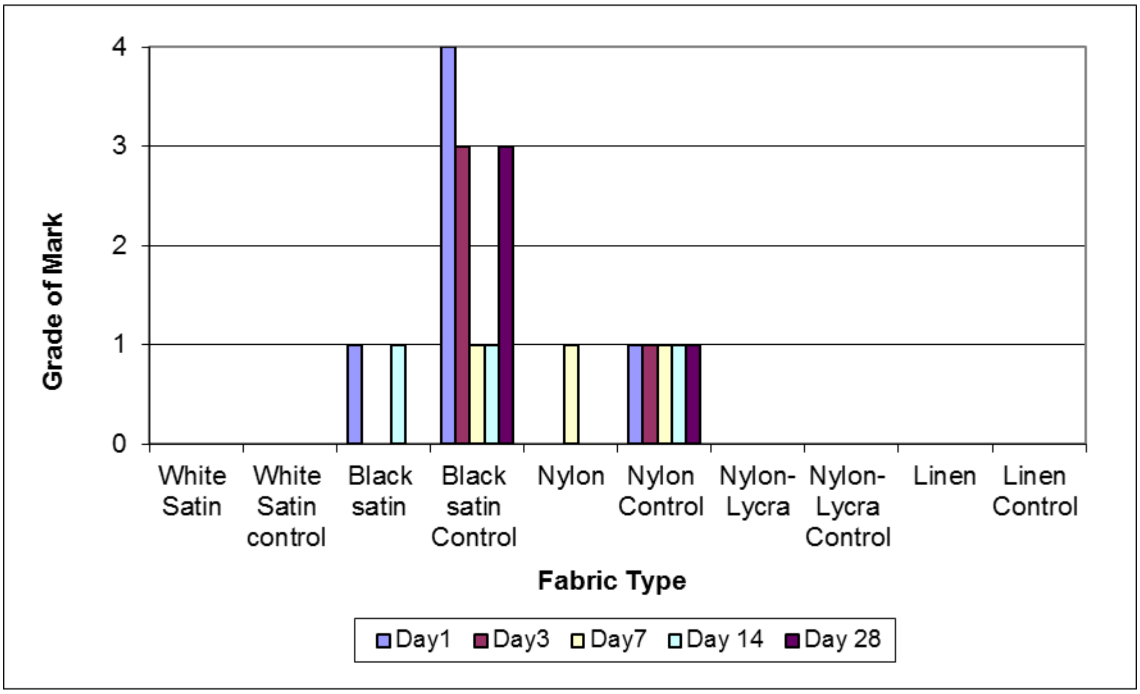


Figure 8.20: Donor three: grades of all samples and controls visualised with CAF. One half of each sample was subjected to simulated dew while the other half acted as a control with no water added.

Though donor three [Figure 8.19] had the highest graded samples with grades 4 and 3 for black satin s/he only had the second highest number of positive samples – 13 compared to 17 for donor one and 11 for donor two. They were negative for white satin, nylon-Lycra and linen. This was not as predicted as this donor was considered a good donor, therefore would have been expected to have the highest number of positive samples compared to the other two donors. The nylon control was graded as 1 for all days, with only day 7 of the treated giving any positive samples (grade 1). The black satin, as with both the other donors, was the most successful – all the controls had positive grades ranging from 1 to 4, however it was only days 1 and 14 of the treated samples that gave positive marks (grade 1). This illustrates that the moisture has had an effect on the visualisation of marks for this donor.

8.4.3 CAF Treatment 3 – heavy rain

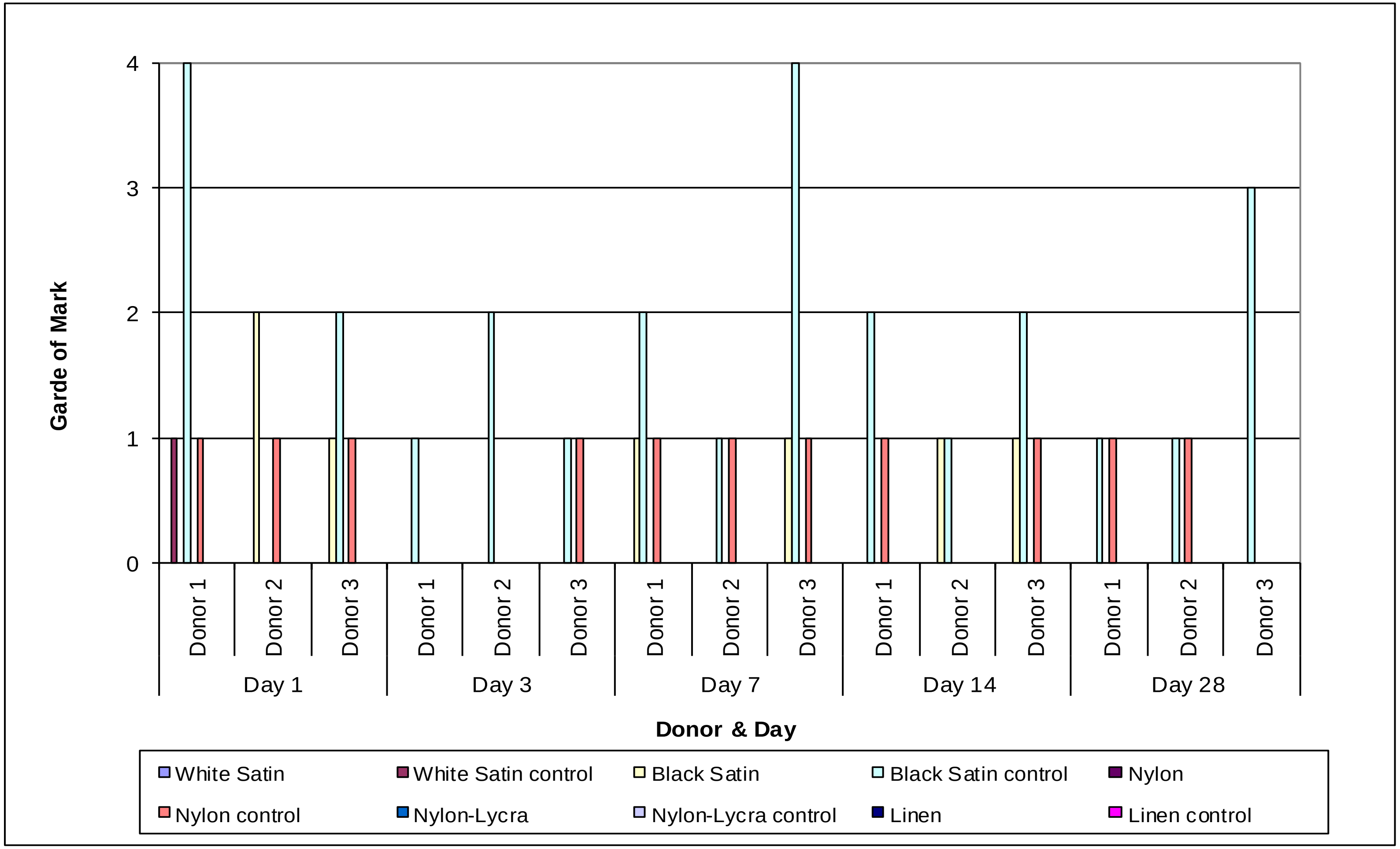


Figure 8.21: Overall results of controls and samples subjected to simulated heavy rain on CAF processed fabrics and controls for a good, medium and poor donor over 1, 3, 7, 14 & 28 days.

Overall effect of heavy rain on fabrics

This set [Figure 8.21] has the least number of samples, both controls and weathered, that were positive for marks. There were 32 marks in total (6 for treated and 26 for controls), compared to 51 for the dew set (22 for treated and 29 for controls) and 40 for moderate rain (12 for treated and 28 for controls). Of the positive samples there were only six grade 2, one grade 3 and two grade 4 samples, therefore only nine samples (6 %) in total that contain any ridge detail that could aid in identification. It can clearly been seen that the water sprayed onto the samples (approximately 15 mL) did have a detrimental effect. Three of the fabric types (white satin, black satin and nylon) had positive samples for the controls (ranging from 1 to 4), while the areas subjected to the water only had positive samples for black satin.

Therefore it must be considered that the water has either allowed the residues to penetrate the fabric surface or they were rinsed away so there was nothing for the CA to bind to and produce polymers thus no visualisation of ridge detail.

Donor one

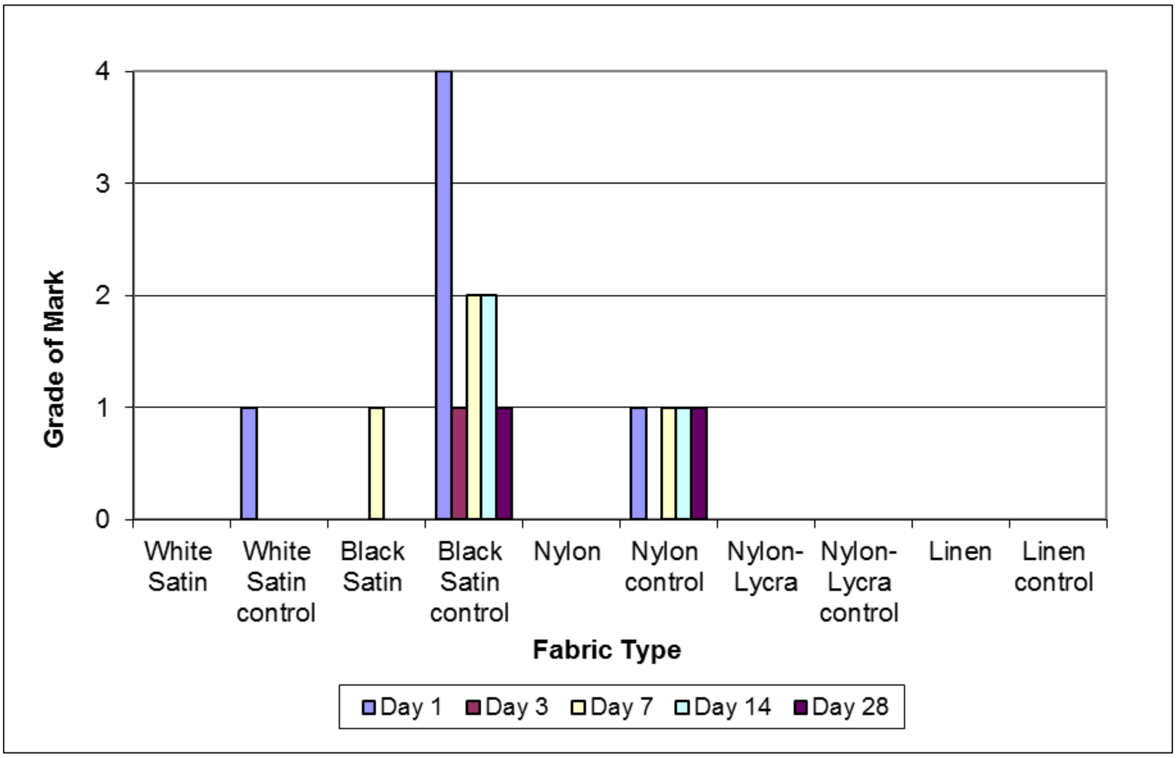


Figure 8.22: Donor one: grades of all samples and controls visualised with CAF. One half of each sample was subjected to simulated dew while the other half acted as a control with no water added.

With the exception of day 1 control, donor one [Figure 8.22] had no positive samples for nylon-Lycra, linen or white satin. While nylon control samples fared slightly better with all, except day 3 (grade 0) being positive for touches (grade 1). It was the black satin controls once again that had the highest grades and the most positive samples, however all the weathered samples were negative except day 7 which had a grade of 1. This would seem to add to the opinion that the simulated heavy rain has washed off any residues, which would have allowed CAF enhancement. It also seems to reinforce the hypothesis that it is the smoother tighter weave fabrics which allow CAF visualisation. The fabrics with positive marks are nylon and black satin both of which are smooth and have the tightest weaves out of the five fabrics tested.

Donor two

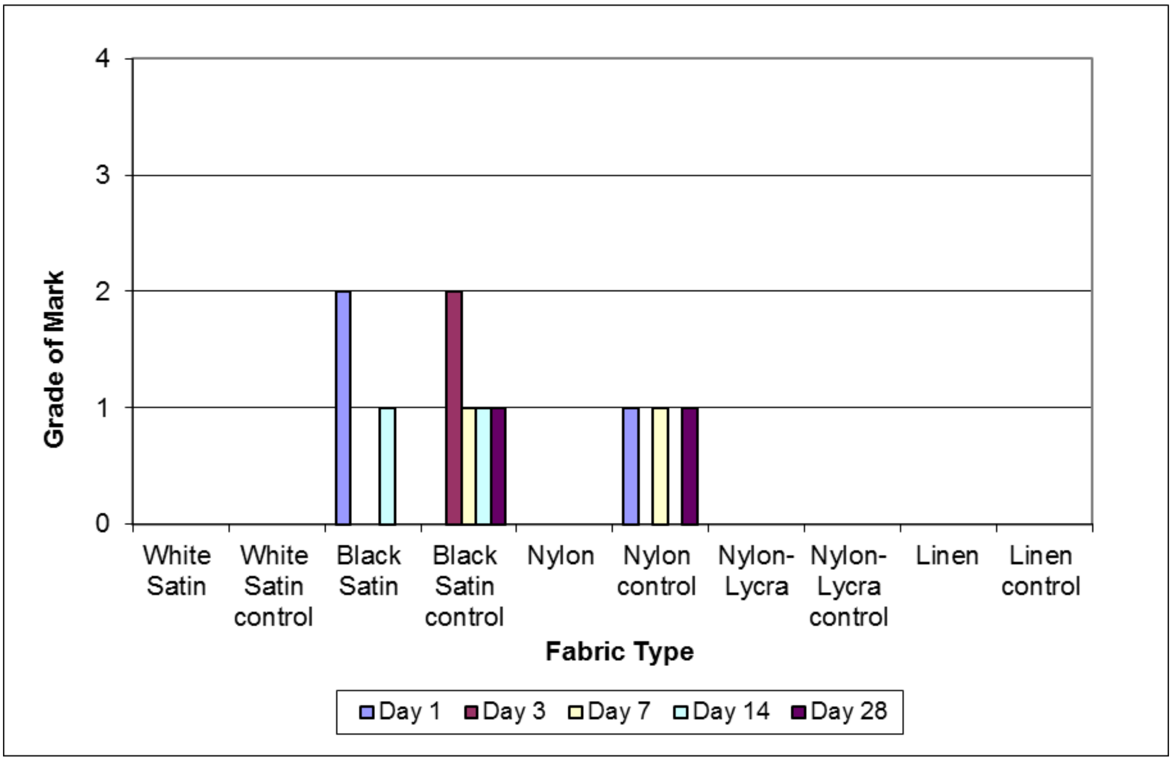


Figure 8.23: Donor two: grades of all samples and controls visualised with CAF. One half of each sample was subjected to simulated dew while the other half acted as a control with no water added.

Again donor two [Figure 8.23] had the lowest grades overall with only 7 on controls and 2 on the treated though interestingly one of the weathered samples (day 1 grade 2) was negative on the control. This may have been due to several factors, such as residues on the donor's hand or the force in which each half of the hand held the fabric. This donor is generally a poor donor therefore these results are not unexpected and the positive samples were on nylon and black satin, which have consistently resulted in positive marks.

Donor three

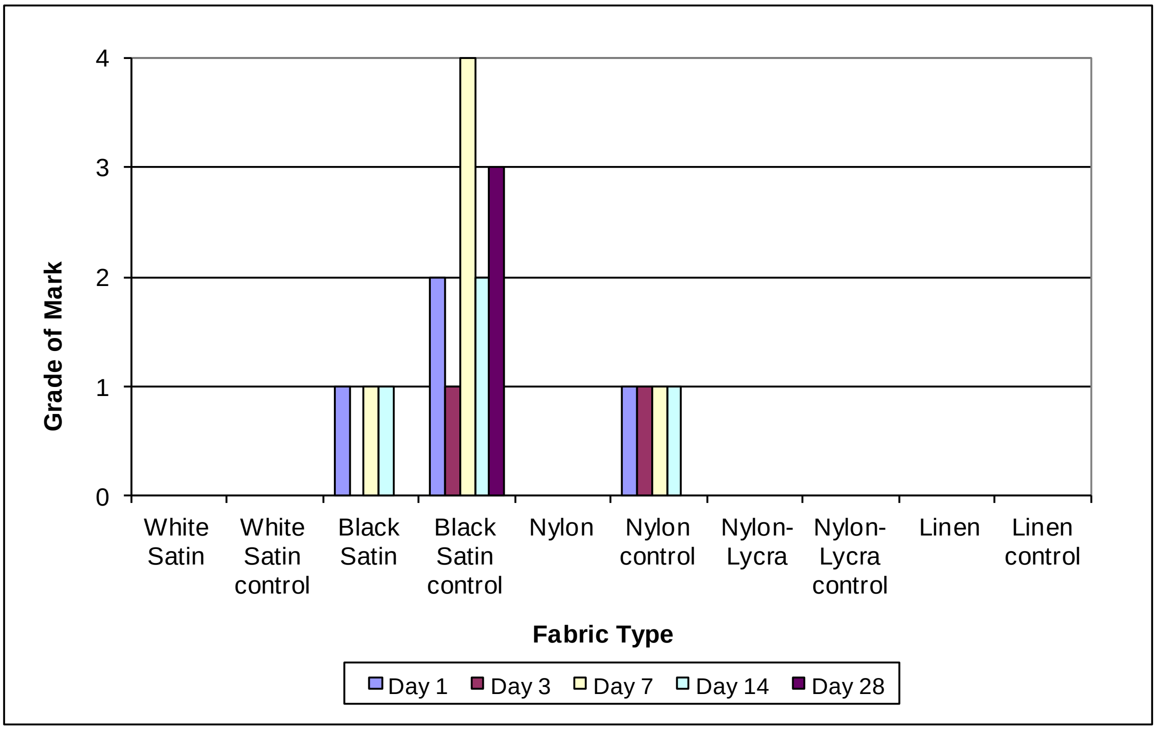


Figure 8.24: Donor three: grades of all samples and controls visualised with CAF. One half of each sample was subjected to simulated dew while the other half acted as a control with no water added.

Donor three [Figure 8.24] was negative for any marks on the controls and treated on nylon-Lycra, linen and white satin as well as treated on nylon. The nylon controls were positive for touches on all days except day 28, while the black satin control samples were positive for all days ranging from 1 (day 3), 2 (days 1 and 14), 3 (day 28) and 4 (day 7).

Overall, the results for CAF were as expected – an increase in moisture led to a decrease in visualisation. Dew had the highest number of marks 34 % with 11 % of these with ridge detail, moderate rain showed 27 % positive marks and 8 % ridge detail, and heavy rain with 21 % and ridge detail 6 %. This is expected as CAF is generally not considered for productions that have been subjected to adverse weather conditions (Yamashita and French 2011). There was a difference in detail observed between each condition and the control samples. This is most likely due to the residue levels on the donors' hands on the day of collection as it is possible for a good donor to have a day where their residue levels are reduced as a result of a reduction in temperature or ill health. A way to confirm this would be to use an artificial residue and stamp rather than a living individual and their natural level of residues. However, the research was attempting to simulate a real-life scenario, such as an assault through grabbing or pushing, which could not be reproduced with a stamp.

8.5 Statistical analysis of the effect of varying levels of water on the fingermark visualisation using VMD and CAF.

The Mann-Whitney U test [Table 8.1] was first carried out to determine which technique, VMD or CAF, was most effective in allowing fingermarks to be visualised on the various fabrics (white satin, black satin, nylon, nylon-Lycra and linen) under each condition (dew, moderate rain and heavy rain) as well as the controls which were not exposed to the water. The null hypothesis (H_0) is therefore no difference between fabrics when the visualisation technique is VMD or CAF, and the alternative hypothesis (H_A) is that there is a difference between the fabrics. The p-value of <0.001 indicates that there is indeed a difference between the two techniques of VMD and CAF and that therefore the H_A must be accepted and H_0 rejected.

Table 8.1: The Mann-Whitney U test of the five fabric samples visualised with VMD or CAF after half of the samples had been exposed to the different water conditions, while controls were left unexposed. Details include number of samples, mean rank, sum of ranks, Mann-Whitney U value and p- value.

	Number of samples	Mean Rank	Sum of Ranks	Mann-Whitney U value	p-value
Dew					
VMD	150	185.22	27782.50	6042.000	0.000
CAF	150	115.78	17367.50		
Moderate rain					
VMD	150	190.95	28642.00	5183.000	0.000
CAF	150	110.05	16508.00		
Heavy rain					
VMD	150	190.08	28512.50	5312.500	0.000
CAF	150	110.92	16637.50		

Each condition had the same number of VMD and CAF treated samples (150), therefore a direct comparison could be carried out. In each case it was VMD that had the higher mean ranks – 185.22 for dew, 190.95 for moderate rain and 190.08 for the heavy rain, compared to CAF with 115.78 for dew, 110.05 for moderate rain and 110.92 for heavy rain. Therefore, the fact that the mean rank values and the sum of ranks are so much higher for VMD compared to those observed for the CAF means that it is the VMD technique that is more effective at allowing the enhancement of fingermarks on the fabrics tested.

As the controls and the samples that have been treated with the various levels of water have been combined for this test it is not possible to conclude which weather condition has had the most effect on the method used to visualise the planted fingermarks. Therefore, the next three tables of Kruskal-Wallis test results [Table 8.2 - Table 8.4] have been separated out into the three different conditions, thus allowing the effect on each weather condition to be determined separately on each fabric tested.

With dew [Table 8.2] the mean rank values show that in each case the controls and those treated showed there is a definite order in which the fabrics show detail, though the order changes depending on the visualisation technique and whether the samples have been treated with water or not.

When considering the control samples that were visualised with VMD, the fabric order determined by the mean rank values is nylon (51.67), white satin (46.20), nylon-Lycra (39.83), linen (29.00) and then black satin (23.30). These results reinforce the opinion that it is indeed the smoothness of the fabric surface and the tightness of its weave that allows increased detail to be observed. When the fabrics tested in this section are considered, the first three fabrics with the highest mean rank values (nylon, white satin and nylon-Lycra) all have smooth surfaces and tight weave structures. The next fabric, linen, is not as smooth and has a more open weave structure. The only fabric that does not follow this pattern is black satin and even though it is a smooth fabric and has a tight weave it had the lowest mean rank value. This is therefore unexpected, however may be explained by the inexperience of the researcher in using silver metal for VMD and that there is less contrast between the dark colour of the fabric and the silver deposited during VMD.

A similar pattern can be seen with the dew treated samples that were visualised with VMD with the highest to lowest mean rank values being nylon (48.27), white satin (46.87), linen (33.33), nylon-Lycra (32.87) and black satin (28.87). Linen and nylon-Lycra however have changed position in the order of detail visualised, though this change could be explained by the addition of water to the samples prior to treatment with VMD. This could either cause the loss of residues by dilution and absorption into the fabric or evaporation of the water, therefore there being less for the VMD to adhere to and visualise. This difference in the controls and water treated samples can also be seen with the p-values of <0.001 for the controls and 0.005 for the treated samples. These p-values also reinforce that the fabrics are different as both values indicate that the H_A needs to be accepted and H_0 rejected.

Table 8.2: Kruskal-Wallis test of the five fabrics processed with VMD or CAF after half of the samples had been exposed to dew water conditions, while controls were left unexposed. Details include number of samples, mean rank, sum of ranks, Kruskal-Wallis value and p-value.

	Number of samples	Mean Rank	Kruskal-Wallis value	Degrees of Freedom	p-value
VMD Control					
White satin	15	46.20	21.116	4	0.000
Black satin	15	23.30			
Nylon	15	51.67			
Nylon-Lycra	15	39.83			
Linen	15	29.00			
VMD Dew treated					
White satin	15	46.87	15.067	4	0.005
Black satin	15	28.87			
Nylon	15	48.27			
Nylon-Lycra	15	32.87			
Linen	15	33.33			
CAF Control					
White satin	15	32.30	51.263	4	0.000
Black satin	15	64.37			
Nylon	15	46.33			
Nylon-Lycra	15	23.50			
Linen	15	23.50			
CAF Dew treated					
White satin	15	29.27	48.583	4	0.000
Black satin	15	63.17			
Nylon	15	43.57			
Nylon-Lycra	15	27.00			
Linen	15	27.00			

With the CAF visualised samples the mean rank values illustrate the expected results if the fabric weave is considered – smoothest to roughest. Black satin (64.37 for control and 63.17 for treated); nylon (46.33 for control and 43.57 for treated); white satin (32.30 for control and 29.27 for treated) with nylon-Lycra and linen (23.50 for control and 27.00 for treated) being joint last. This order is similar to that of the

VMD treated samples, with black satin being the only significant difference. This could be explained by the fabric being black, the CA polymer yellow/white and there being less background fluorescence, therefore the marks were easier to see. Thus, the data illustrates that the fabrics were in fact different, which is reinforced by the p-values of <0.001. Therefore the H_A should once again be accepted and the H_0 be rejected.

With the moderate rain results [Table 8.3] the control samples could be ranked with their mean rank values illustrating the order of fabrics with the highest level of detail: white satin (53.00), nylon (51.70), nylon-Lycra (37.17), linen (25.03) and black satin (23.10). This is also the order of smoothness of the fabric surfaces, with the exception of the black satin. This would be as expected if the hypothesis that the smoother the fabric the more detail is visualised. The fact that less detail was observed on the black fabric could, as suggested earlier, be due to the fabric and VMD metal colour not allowing enough contrast for the detail to be observed. The order with the treated samples was different: nylon (52.00), white satin (42.23), joint black satin and nylon-Lycra (32.17) and linen (31.43). This change in order may be due to the addition of water to the samples, in that white satin absorbs more water than the nylon and therefore could have influenced the results obtained. The p-values illustrate that the fabrics were different (p<0.001 for controls and 0.009 for treated), even with two of the treated samples having the same mean rank (treated black satin and nylon-Lycra, 32.17) the H_A should be accepted and the H_0 rejected.

The results for the control and treated CAF samples, though having different mean rank values, follow the same order ranking: black satin (62.27 for the control and 54.13 for the treated); nylon (51.20 for the control and 38.90 for the treated); white satin (28.53 for the control and 33.97 for the treated) and, jointly, nylon-Lycra and linen (24.00 for the control and 31.50 for the treated). The higher levels of detail observed would be expected if the hypothesis of the smoothness of the fabric surface and tightness of weave applied. Therefore the fabrics can be considered different and this is reinforced by the p- values both being <0.001. Thus once again the H_A should be accepted and the H_0 rejected.

Table 8.3: Kruskal Wallis test of the five fabrics processed with VMD or CAF after half of the samples had been exposed to moderate rain conditions, while controls were left unexposed. Details include number of samples, mean rank, sum of ranks, Kruskal-Wallis value and p-value.

	Number of samples	Mean Rank	Kruskal-Wallis value	Degrees of Freedom	p-value
VMD Control					
White satin	15	53.00	28.945	4	0.000
Black satin	15	23.10			
Nylon	15	51.70			
Nylon-Lycra	15	37.17			
Linen	15	25.03			
VMD Moderate Rain Treated					
White satin	15	42.23	13.447	4	0.009
Black satin	15	32.17			
Nylon	15	52.00			
Nylon-Lycra	15	32.17			
Linen	15	31.43			
CAF Control					
White satin	15	28.53	53.702	4	0.000
Black satin	15	62.27			
Nylon	15	51.20			
Nylon-Lycra	15	24.00			
Linen	15	24.00			
CAF Moderate Rain Treated					
White satin	15	33.97	26.510	4	0.000
Black satin	15	54.13			
Nylon	15	38.90			
Nylon-Lycra	15	31.50			
Linen	15	31.50			

The heavy rain results [Table 8.4 and 8.5] though not in the expected orders do again show that all the fabrics are different with p- values of 0.000 and 0.004 for the control and treated respectively. The mean rank values also allow the fabrics to be ranked in order of the level of detail observed. The VMD control samples could be ranked in order of most to least detail as white satin (48.40), linen (34.73), nylon-Lycra (33.73), nylon (25.80) and black satin (20.33). While the treated samples can be ranked nylon (48.17), white satin (47.20), linen (35.63), black satin (34.17) and nylon-

Lycra (24.83). While the order for the CAF treated samples is, for the controls, black satin (63.20); nylon (49.57); white satin (27.33) with joint for nylon-Lycra and linen (25.00). The treated samples had the black satin ranked first with a mean rank value of 50.00 and all the other fabrics (white satin, nylon, nylon-Lycra and linen) with the value of 35.00. The reduction in differences between the values for the treated samples could be attributed to the water being added to the samples and therefore the removal of residues, thus decreasing the residues remaining to be visualised. However, this would not explain the difference in the values and order observed in the VMD control samples. Therefore, this must be due to some other variable, such as the donors and the level of residues on their hands at the time of deposition.

Again with both the VMD samples (controls and treated) and CAF samples (controls and treated) the p-values were all <0.001, therefore as the p-value is <0.05 the H_A should be accepted and the H_0 rejected.

Table 8.4: Kruskal Wallis test of the five fabrics processed with VMD after half of the samples had been exposed to heavy rain conditions, while controls were left unexposed. Details include number of samples, mean rank, sum of ranks, Kruskal-Wallis value and p-value.

	Number of samples	Mean Rank	Kruskal-Wallis value	Degrees of Freedom	p-value
VMD Control					
White satin	15	48.40	25.082	4	0.000
Black satin	15	20.33			
Nylon	15	25.80			
Nylon-Lycra	15	33.73			
Linen	15	34.73			
VMD Heavy Rain Treated					
White satin	15	47.20	15.367	4	0.004
Black satin	15	34.17			
Nylon	15	48.17			
Nylon-Lycra	15	24.83			
Linen	15	35.63			

Table 8.5: Kruskal Wallis test of the five fabrics processed with CAF after half of the samples had been exposed to heavy rain conditions, while controls were left unexposed. Details include number of samples, mean rank, sum of ranks, Kruskal-Wallis value and p-value.

	Number of samples	Mean Rank	Kruskal-Wallis value	Degrees of Freedom	p-value
CAF Control					
White satin	15	27.23	54.607	4	0.000
Black satin	15	63.20			
Nylon	15	49.57			
Nylon-Lycra	15	25.00			
Linen	15	25.00			
CAF Heavy Rain Treated					
White satin	15	35.00	25.714	4	0.000
Black satin	15	50.00			
Nylon	15	35.00			
Nylon-Lycra	15	35.00			
Linen	15	35.00			

Overall, with the various levels of water added to the samples, both the control and treated samples have extremely low p-values – all the controls were 0.000, while the VMD treated samples - dew (0.005), moderate rain (0.009), heavy rain (0.004) were all higher. Therefore there is a definite difference between all the fabrics tested when visualised by either VMD or CAF and thus the H_A should be accepted in all cases.

8.6 Comparison of VMD and CAF

When comparing the two different techniques it appears that water has had a similar effect on both, with a reduction in the number of positive samples and the level of detail, though this is more dramatic with CAF. The data shows that there is quite a difference between the VMD and CAF, however this is as expected, when the literature indicates that VMD can visualise marks after the substrate has been subjected to moisture, but CAF is not effective at visualising marks after similar treatment (Yamashita and French 2011). The dew had a high level of positive marks for the VMD (82 %) while the CAF samples only had 34 % positive marks. The difference with the moderate rain samples is even higher – VMD had 79 % of positive marks, while the CAF was only 27 %. With the heavy rain there was a difference of 53 % between the VMD (74 %) and the CAF (21 %). The level of detail is also higher in the VMD samples compared to the CAF samples – dew had 22 % of the samples showing ridge detail, whereas CAF only had 11 %; moderate rain had 27 % for VMD and only 8 % for CAF; finally, with heavy rain VMD had 23 % and CAF 6 %. All this illustrates that VMD is indeed more effective at visualising fingermarks, grabs and marks on items that have been wetted. Though the techniques have both been affected by the level of water added to them there is also an effect from the donor and the fabric being tested on the level of detail visualised.

There is a definite trend in donors with donor one being a medium donor in most other studies and in this case, one was found to be the same; while donor two had always been considered a poor donor, which was the same in this study; finally donor three is a good donor in all trials. There were some exceptions to this however, as donor one CAF, in the moderate rain, was only slightly better than donor two who was considered a poorer donor. Therefore this illustrates that even though donors can be given a general classification this is not always the case as there can be many factors that influence the secretions produced by a person, such as their sex, occupation, whether they have applied cosmetics or even ran their hands through their hair (Yamashita and French 2011). All of these factors could result in the donor leaving poorer or better quality latent fingermarks.

There was a difference in the order of the fabrics that allowed visualisation of ridge detail, and this is reinforced by the statistical tests carried out and described in section 8.5. The order for the VMD samples was nylon, white satin, nylon-Lycra, linen and black satin, while that for the CAF samples was black satin, nylon, white satin, and then nylon-Lycra and linen being tied for last place as neither visualised any detail or marks. The order is similar and the difference in position of the black satin could be attributed to there not being background fluorescence from the BY40 therefore more detail could be seen, while with the VMD, the operator was unfamiliar with the use of silver VMD therefore this may have affected the level of detail observed. When the smoothness of the fabric surface is considered, it was nylon, nylon-Lycra, white and black satin, linen. The order of the detail observed with both techniques seems to follow the same order; the smoother the surface of the fabric the more detail observed. The absorbency (most to least absorbent) is linen, nylon-Lycra, black satin, white satin, nylon and appears to follow the opposite order. This makes sense as the more water a fabric will absorb the less residues will remain on the surface as they will most likely be absorbed into the fabric or washed off and not be available to the visualisation technique.

Examining of the grades, in conjunction with the different weather treatments, indicates that the level of detail has been affected by increasing amounts of water. With VMD, the most grade 0 samples can be found in the heavy rain treatment (30 samples), followed by moderate rain (20 samples), then lastly dew (19 samples). This would be expected if water is having a detrimental effect on visualisation. With grade 1, the opposite can be seen as dew has the highest number (51 samples), the moderate rain (45 samples) and lastly heavy rain (40 samples), though again this would be expected as more water would lead to less detail. Grade 2 does not really follow the trend of more water less detail as moderate rain had the highest number of samples (nine), followed by dew (five) and then heavy rain (four). Therefore, this could be a result of donor effects – their ability to leave good detail or that their residues may not have been at suitable levels to leave good detail. With grade 3 samples, as there were only two – one after the moderate rain and the other after heavy rain, this shows water is having an impact of the quality of detail visualised. With the CAF samples the expected trend is observed with an increase in negative samples as the water levels increase - dew (52 samples), moderate rain (62 samples) and heavy rain (69 samples). The number of positive samples decreases as the water levels increase – for grade 1 dew had fifteen positive samples, moderate rain twelve and heavy rain five. With grade 2, dew had six samples, moderate rain zero, and heavy rain one, so a slight deviation from the expected. Finally, grade 3 samples only had two positive samples – one for dew and one for moderate rain, which could be expected, the more water added to the samples the less detail observed. Both techniques are thus following the expected trends of more water leading to less detail visualised.

8.7 Hydrophobicity and hydrophilicity of fabrics

As discussed in the introduction (Section 1.2.1 and 1.2.2), most fabrics absorb moisture from their surroundings, but how much depends on the chemical and physical properties of the fabric. Also, natural fibres tend to be more hydrophilic and have a higher percentage regain, whereas manmade fibres are the opposite. Thus, it would be expected that this would have an effect on how fingerprint residues would sit on the fabric surface, how much would be available for fingerprint processing techniques, and how much dye would be taken up during CAF processing. Therefore, a small absorbency study (as described in section 2.14.2) was embarked upon to attempt, in a simplistic manner, to determine whether the uptake of water by a selection of fabrics could give some explanation into the hydrophilic or hydrophobic nature of the fabrics. Such an insight may help explain the results observed in the previous sections and whether it is the hydrophobic nature of the fabrics that allow the fingerprint residues to sit on the fabric surface and be available for visualisation.

The water resistance rain test (AATCC 2006) was originally going to be used to test the absorbency of the fabrics, as it was thought this would be the best way to ascertain how much water would be absorbed from rain like conditions. This test involves water being sprayed for 5 minutes onto a fabric swatch which is backed with a blotter, then after the 5 minutes, the blotter is weighed and the water absorbed is measured. However, due to constraints with equipment and that the measurement determined how much water went through the fabric rather than being absorbed by the fabric it was decided that another test needed. Therefore, it was decided to use the absorbency test from the Texwipe (2011) website, where the swatches were weighed, placed in water for 1 minute, removed, shaken and reweighed.

Table 8.6: Hydrophobicity and hydrophilicity testing of the nine fabrics. The samples were weighed dry, wetted, after drying and then three more times after 1, 3, 7, 14 and 28 days. The average weights from triplicate measurements were used to determine the percentage weight gain.

Fabric type	Weight (g)								
	Initial	Wet	After drying	After 1day	After 3 days	After 7 days	After 14 days	After 28 days	Intrinsic Absorbency Value (mL/g)
Polycotton	1.6538	1.9167	1.6506	1.6516	1.6547	1.6509	1.6578	1.6544	0.16
Nylon-Lycra	2.9831	3.3149	2.923	2.9881	2.9905	2.9896	2.9841	2.9743	0.11
Nylon	1.8352	1.9648	1.8064	1.8293	1.8423	1.8169	1.8156	1.8174	0.07
Linen	1.3058	1.9195	1.2712	1.309	1.3008	1.3101	1.3064	1.2866	0.47
Silk	1.1564	1.8653	1.1574	1.1568	1.1574	1.1568	1.1573	1.1571	0.61
Black Satin	3.8352	4.7748	3.8064	3.8293	3.8423	3.8169	3.8156	3.8174	0.25
White Satin	2.3485	2.8293	2.5595	2.3442	2.3473	2.3495	2.3381	2.3086	0.20
Polyester	1.6738	1.8396	1.6606	1.6616	1.6647	1.6611	1.6678	1.6744	0.10
Cotton	1.6567	2.3196	1.6585	1.6546	1.6553	1.6536	1.656	1.6554	0.40

Overall, the order of absorbency determined (Table 8.6) by the fabric intrinsic absorbency values was silk (0.61), linen (0.47), cotton (0.40), black satin (0.25), white satin (0.20), polycotton (0.16), nylon-Lycra (0.11), polyester (0.10) and nylon (0.07). This does seem, in part, to confirm the hypothesis that the natural fabrics are more absorbent, or hydrophilic, than the manmade fabrics. The three pure natural fabrics, silk, linen and cotton were the first, second and third most absorbent fabrics. A similar test was carried out by Tri-Sis Inc. (no date) in which it was determined that natural fabrics absorbed the most water – cotton (50 to 60 %), wool (40 %) and rayon as much as 95 %. Thus, the results obtained in the current study are quite similar as the intrinsic absorbency value, if converted to a percentage, would show that cotton absorbed 40% of its dry weight. The mixed fabric, polycotton was at the lower end of the absorbency spectrum and this could be due to the 40 % polyester component of the fabric, which could be increasing the hydrophobicity. Therefore polycotton is more absorbent than polyester by itself, but less absorbent than cotton alone. The three fabrics with the lowest absorbency were nylon-Lycra, polyester and nylon, all of which are manmade, therefore would be expected to be less absorbent and more hydrophobic. The Tri-Sis Inc. (no date) states that polyester absorbed 3 to 5 % with nylon absorbing 11 to 12 % but the results obtained in this study were slightly different with nylon being 7 % and polyester 10 %. The results confirmed that there is a reduced level of water absorption in these fabrics and lack of water uptake was most likely due to surface coatings or treatments, as well as physical and chemical properties of the fabrics.

All the fabrics adhered to the Home Office suggestion (Bowman 2005) of a minimum of three threads per millimetre (mm) with silk having the highest thread count of six, the satins, polyester and nylon-Lycra all had four and nylon, polycotton, cotton and linen had three threads per mm. The more threads per mm in the fabric would produce tighter weave, though this is not always the case, as weave also relates to the size of the fibres themselves. Silk had the finest and highest number of threads per mm with six, which led to the tightest weave, but the satins and nylon-Lycra had a comparable tightness to their weave, but with less fibres. Nylon was the next tightest weave fabric, though the three fibres per mm were quite large thus leading to a tighter weave. Polyester had one more thread per mm (four), but it had a more open weave when compared to nylon. The remaining fabrics all had three threads per mm, but how they were woven together affected the tightness of the weave with polycotton having the tightest weave, even though it comprised of threads differing in size.

Cotton had quite evenly sized threads, but they were larger and looser in how they were woven together. The final, and most loosely and open woven fabric, was linen which comprised of alternating thick and thin threads and many loose fibres.

The smoothness of the fabrics did not follow the same pattern as the tightness of the weave and was, in order, nylon, nylon-Lycra, satin, silk, polycotton, polyester, cotton and linen. Nylon was more open than nylon-Lycra but the fibres themselves were smaller, while the nylon-Lycra weave was rougher or "lumpier" in appearance. Satin had a more even surface with no loose fibres and silk had a "bumpy" surface, though there were no loose fibres, whereas polycotton and polyester had a few loose fibres on their surface. The number of loose fibres was higher with cotton and linen, which, in turn increased the roughness of the surface. Therefore, there are several aspects that need to be considered when determining the absorbency as well as how hydrophobic or hydrophilic a fabric is and therefore the effect this could have on the level of detail visualised. The tightness of weave, number of threads, composition of the fabric, and therefore the effect these have together on ridge detail visualised.

Overall, it does appear that natural fibres absorb water more than manmade fibres, thus it would be expected that the natural fabrics would therefore absorb more of the fingerprint residues, as they are 95 % water (Bowman 2005; Girod, Ramotowski and Weyermann 2012) and this would probably impact negatively on the level of detail visualised. This does seem to be the case when the fingermark gradings of each fabric, reported in the previous chapters is considered. It does indeed appear that the majority of the natural fabrics did not show much or any fingermark detail, whereas the manmade fabrics allowed high graded marks to be visualised. There were however exceptions: in some instances silk had high gradings, whereas polyester had low grading, therefore this demonstrates that it is not only the hydrophobicity, but the fabric and even the donor that has an effect on the level of detail visualised.

8.8 Effect of washing on fabric surface texture

When considering the previous results it can be concluded that the structure and properties of the fabrics are important with regard to the level of detail visualised. This does not just apply to the chemical properties and their weave, but also if coatings have been applied or surface damage due to washing. Therefore a mixture of manmade and natural fabrics (cotton, linen, nylon-Lycra, polycotton, polyester, satin and silk) were utilised in these studies to determine the effect, if any, of washing on the fabric surfaces. Thus, all the fabrics were photographed using a x 200 Veho™ Discovery™ VMS-001 Universal serial bus (USB) microscope when they were new and unwashed. How the unwashed fabrics appeared can be seen in the first column of images in Figure 8.25, then all the fabrics were washed one time (second column), re-photographed, washed another 4 times and re-photographed (third column), then finally washed again until they had been washed a total of twenty times and re-photographed once more (fourth column). Even after twenty washes, many of the fabrics felt and appeared visually the same, with only cotton, linen, nylon and polycotton appearing slightly different. However the washing did not appear to have any effect on surface morphology of nylon-Lycra, polyester, satin or silk. Therefore, the effect of surface defects, printed patterns and the actual wearing of the fabrics, as well as potential wear and tear must have more effect than washing alone on the surface structure of the fabric. This effect of washing was examined on a bigger scale in a final year student project examining the effect of washing on the level of fingermark detail visualised using CAF (Davidson 2013) – who, again, took photographs from the initial clean, new, unwashed polycotton and satin fabrics and then after every wash. However, this time the student was also looking at what effect washing had on fingermark recovery. After the fabric had been washed a section was cut off, natural fingermarks were planted in a depletion series and then processed using CAF. Then the remaining fabric was washed again, and the process repeated until all the fabric had been used. The overall results reinforced the findings of this study and showed that there was little physical effect observable on the fabric surface from the repeated washing but there did seem to be an influence on the level of detail visualised. As the washes increased there was a decrease in the number of fingermarks visualised and of these marks the level of ridge detail observed was reduced (Davidson, K. 2013. Pers. comms, 9th May; Davidson 2013).

This could be due to coatings being removed from the fabric surface and making it easier for the residues to be absorbed into the fabric and therefore unavailable for interaction with the CAF. Another reason could have been the addition of optical brighteners from the washing detergent or an improved uptake of the BY40 dye, both of which could have led to increased background fluorescence. This hypothesis will require further testing. It could also mean that the surface morphology was altered, but at a level that could be observed with the USB microscope or photography indicating that it might be chemical rather than physical.

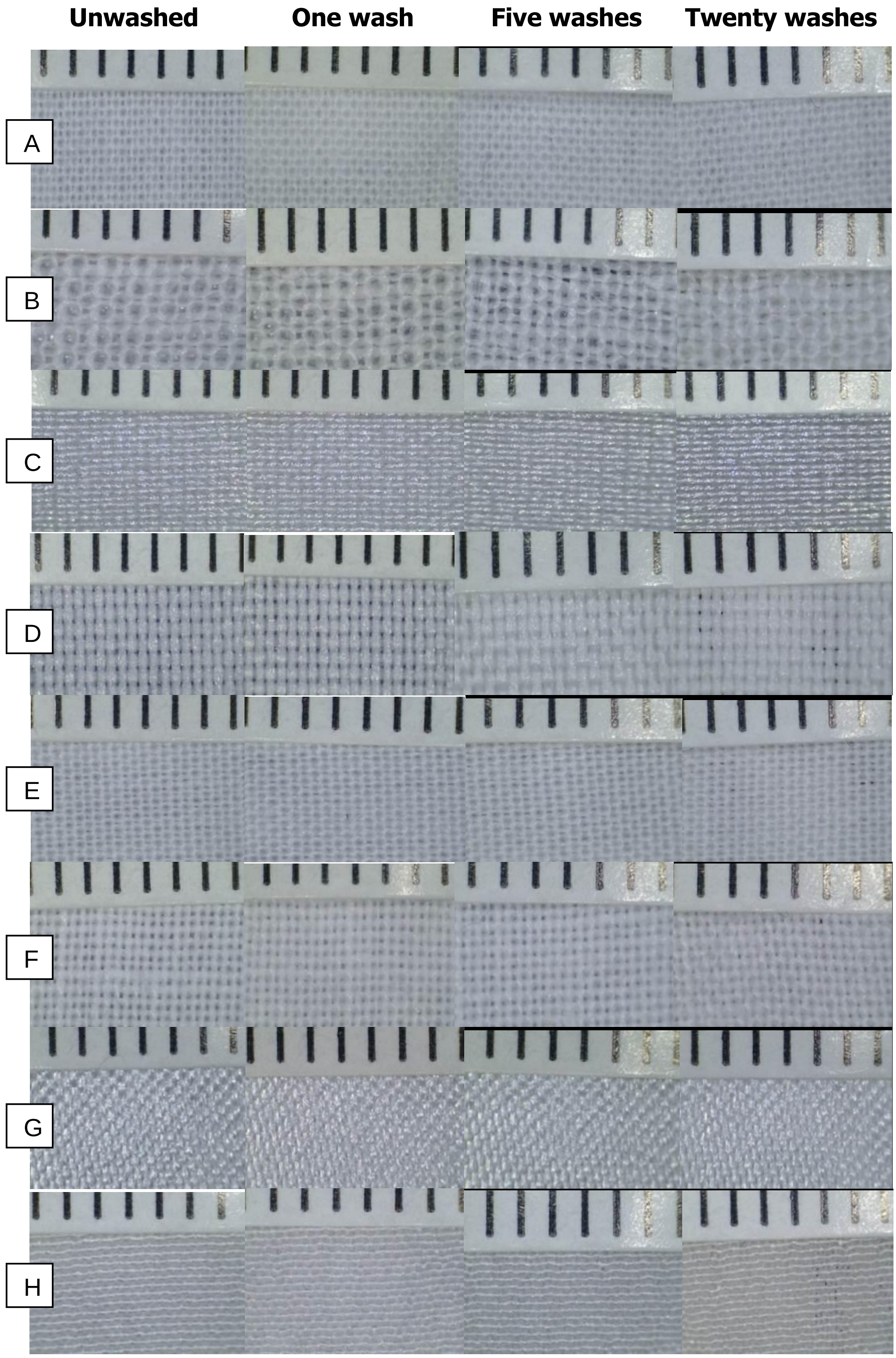


Figure 8.25: Images taken with an x200 magnification USB microscope of the effect of washing on cotton (A), linen (B), nylon-Lycra (C), nylon (D), polycotton (E), polyester (F), satin (G) and silk (H). The first image is of the original unwashed fabric; second image after one wash; third after 5 washes and fourth after 20 washes.

"Wear and tear" or roughing up of a fabric's surface could lead to a reduction in detail. For example, a smooth fabric, such as satin, can become pilled, where small balls from on the surface when different areas of the garment are rubbed together when the item is worn. This could lead to a rough surface, which could then affect the level of detail visualised on a fabric that would normally have allowed good detail to be observed. A small trial on the effect that wear would have on to the fabrics and their ability to allow the visualisation of fingermarks was also performed, though this "did not produce conclusive results" (Davidson, K. 2013. Pers. comms, 9th May). Therefore, more work needs to be performed on the effect of washing as well as "wear and tear" on fabrics and their morphology to fully determine the effect on fingermark visualisation and, therefore, operational use.

The majority of cases that would involve clothing being examined would be assault cases where the most victims are aged between 16 and 24 (13.3 % men and 4.3 % women) (Hall and Innes 2011). However, if the type of assault is of a sexual nature the victims tend to be women and the Office for National Statistics (2013) reports that 3 % of women in England and Wales were the victims of sexual assault during 2011, whereas the percentage for men was 0.3 %. Also, a Scottish Government report (2011) states that these types of crimes occurred in many places, from shops (6 %), the victim's home (11 – 12 %), to their place of work (19 %), however the majority (22 %) occurred when the individual was at a pub or nightclub. Therefore, when considering sexual assaults on young women many could occur on nights out, thus the effect of washing as well as wear and tear may be negligible, as the majority of young women, tend to purchase a new outfit for the occasion.

8.8.1 <u>Effect of water on the fabrics used in this study</u>

Overall, there was a trend with the addition of water to the surface of the fabrics in this study; the more water that was added the level of detail visualised with both VMD and CAF was reduced. This reinforces the literature and experiences of previous researchers as well as those who use the VMD and CAF techniques operationally. It is generally acknowledged that VMD is considered to be a more sensitive technique for the development of marks and marks on items that had been subjected to adverse conditions, such as the item being wetted. Also, it has been suggested that CAF is not a suitable technique to use on wetted items and that it would not be expected to recover detail (Yamashita and French 2001). This is confirmed in this study as VMD visualised more detail and detail of a higher quality than CAF.

It was also seen that the fabrics behaved differently to the various amounts of water added to their surface. For example, the water sat on the surface of nylon with all the conditions, with only a small amount soaking in with the moderate rain conditions though more with the heavy rain. Linen absorbed more water even with the dew treatment as seen when viewed under a microscope. The water beads could clearly be seen tangled in the fibres of the loose weave, and with the heavy rain the water completely soaked into the fabric and the paper towel underneath it. Therefore, the natural fabric, linen is more absorbent than the manmade nylon; this in turn was not unexpected when Geijer (1979) states that linen absorbs water quite easily, while nylon is quite hydrophobic (Hegde et al. 2004). Therefore this and the information gleaned from the hydrophobicity and hydrophilicity study above show that the chemical composition as well as the surface structure has a great effect on how the fabrics behave when they interact with water.

The donor also has an effect on the level of detail visualised with both techniques. A good donor on fabric will usually produce more detail than a medium or poor donor with the detail being of better quality on fabrics that have a tighter smoother weave.

The timeline should also be considered due to the impact of environmental, physical and chemical effects of the composition and length of life of the fingermark. As it ages the water is first to be lost and depending on how porous the substrate is the water-soluble components soak into the substrate and are not available for certain visualisation processes (Champod et al. 2004). Older marks will not be as easily visualised with CAF as it is the water and salts that are needed for this process to work, whereas VMD works best with more oily residues so this is one reason why VMD can visualise older marks. However, during this study older marks have, unexpectedly, been visualised at times when they were not expected. Therefore just because an item is old does not mean there is no possibility of a mark being visualised.

When considering whether to process an item of clothing or textiles there are several factors that need to be considered first: has the item been wetted at any time and to what level; is the item a natural or manmade fabric; and how long has it been between incident, collection and processing. This may help decide what technique is going to be more useful and possibly more successful; however both techniques have shown success in visualising marks and marks of varying levels of detail on many different fabric types and of different ages and consequently both VMD and CAF should be considered as possible techniques for obtaining fingermarks from clothing.

9. DEPLETION SERIES WITH COMPARATIVE VISUALISATION TECHNIQUES

9.1 Aim

To determine the level of fingermark detail that can be visualised from a depletion series with small particle reagent (SPR), ninhydrin, 1,8-diaza-9-fluorenone (DFO) and fluorescent powder from three donors over a 1, 3, 7, 14 and 28 days timeline.

9.2 Results and discussion

This section considers other commonly used fingerprinting techniques, such as SPR, ninhydrin and DFO as well as the more novel technique of fluorescent powders. SPR, which is generally used on non-porous substrate such as plastic bags and glass, interacts with "fatty constituents" to form a dark black/grey mark. Both ninhydrin and DFO react with the amino acids in the fingermarks with the former producing a purple mark (Ruhemann's purple), whereas the latter gives a mark that fluoresces under light in the range of 470 – 578 nm, though it may also produce a pink/purple coloured mark. Both techniques are generally used on porous substrates, such as paper (Bowman 2005). Fluorescent powders adhere to the water in the fingerprint residues but need to be viewed under UV or laser light and can be used on a variety of substrates such as card, wood and metals (Yamashita and French 2011).

All the marks were directly compared to CAF by use of split depletion series [Figure 9.1], thus allowing these techniques to be compared to a methodology that had previously yielded fingermarks and ridge detail on fabrics. However, overall there was little success with any of these techniques. As a starting point a shortened timeline was used (days 1, 3, 7 and 28) and the number of donors was reduced to three. Each technique (SPR, ninhydrin, DFO and fluorescent powders) were compared to CAF by use of a split mark. Split marks were also used to compare the two different types of DFO (the traditional method was compared to the dry method as detailed in the 1995 paper by Bratton and Juhala) and three types of ninhydrin (traditional, using an iron and no heat or humidity).

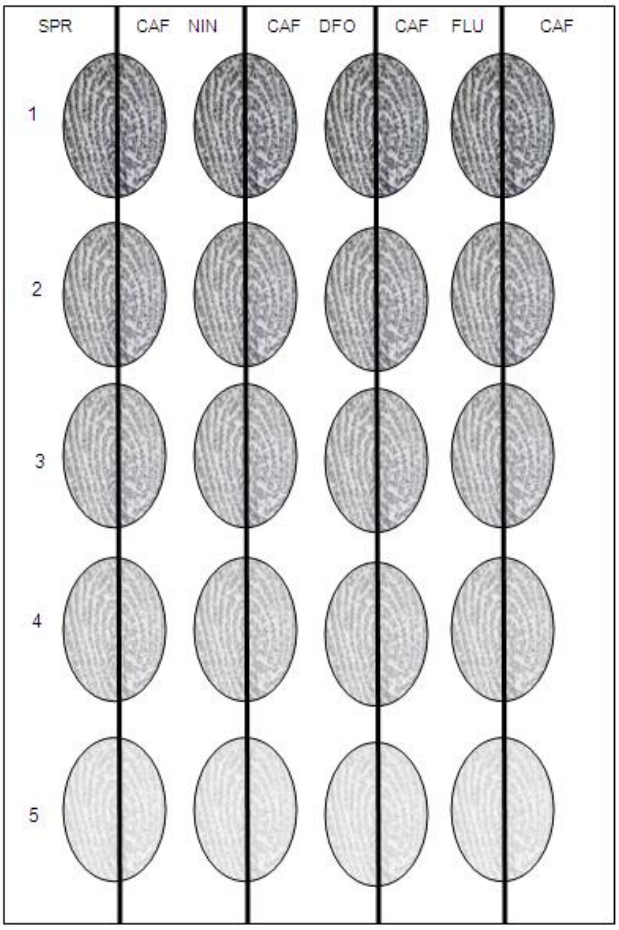


Figure 9.1: Example of fingermark placement for split depletion samples. The donor placed one finger at position 1, and then position 2, without adding any more residues, continuing until position 5 is reached. This would then be repeated for each column of marks, using a different finger each time, until all the positions were filled.

9.2.1 Day 1

SPR had only negative results for all donors and fabrics with the exception of donor one on nylon, which had empty marks at the first three depletions so all were graded as 1 (Home Office grading system) as none had any ridge detail. The CAF split samples were also graded as 1, however all five planted marks were visible with donors one and two. Donor one also had grade 1 marks in depletion positions 1 - 4 on satin and there was a possible mark on polyester for donor three.

With ninhydrin, the fabrics themselves became coloured, ranging in a light pink to a dark blue [Figure 9.2] and this may have been due to the presence of proteins in the fabrics. There were not many marks, and those present, were at the start of the depletion series. Donor one had marks on nylon at depletions one and two and on polycotton at position one, thus grade 1 for all. With donor two, nylon showed faint marks at depletions one to five, but no ridge detail, thus grade 1. These marks corresponded again to the CAF marks i.e. positive depletions one – five for nylon donor one and two, with depletions one – four donor one satin, while all others were negative.

Dry DFO and fluorescent powders were negative for all donors and fabrics. The corresponding CAF samples had limited visualisation also – only positive grade 1 samples for nylon (depletions one – five) for donors one and two.

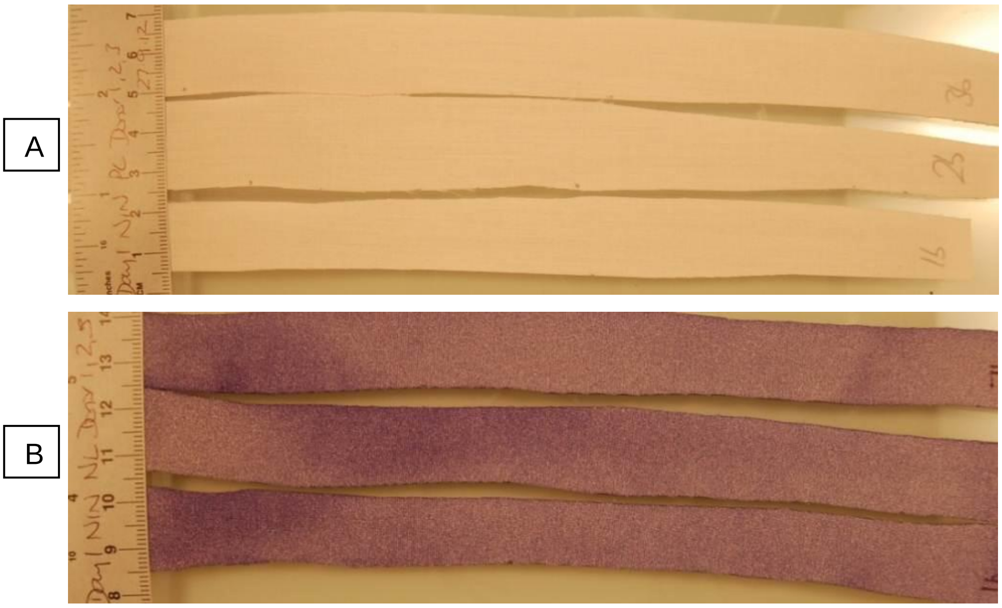


Figure 9.2: Day 1 samples of (A) polycotton and (B) nylon Lycra illustrating the range of colour produced on the different fabrics used in study, after processing with ninhydrin.

9.2.2 Day 3

SPR was negative for all fabrics and donors except nylon which had positive empty marks at depletions one – four, for donor one and three, with only a possible mark at depletion three for donor two. There were positive marks for nylon with all donors at depletions one – five with CAF. Ninhydrin and dry DFO samples all were negative with only discolouration to the fabric surfaces. There were however positive marks with the fluorescent powder – donor three had marks on nylon (depletions one – five) and a possible mark on polycotton (depletion one). Donor one was even more positive with ridged detail at depletion one and two (grade 4, Figure 9.3) as well as depletion five (grade 3) on polycotton fabric. Again, all the corresponding CAF samples only had positive, grade 1 marks for all the donors on the nylon marks (depletions one – five).

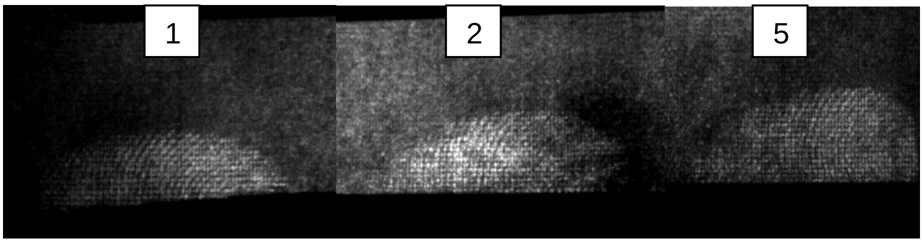


Figure 9.3: Ridge detail at positions 1, 2 and 5 of donor one, day 3 polycotton depletion series. Visualised with fluorescent powder and photographed using a Quaser (white light setting).

9.2.3 Day 7

There were very few positive marks for SPR, ninhydrin or dry DFO. SPR was completely negative for all donors and fabrics. With ninhydrin, there was staining and some positive marks for donor one on nylon, polyester and polycotton, along with donor three on polyester. Dry DFO had a possible mark for donor one on nylon-Lycra. The fluorescent powders had some ridge detail and donor one was the most successful with marks on four of the fabrics (nylon, silk, polycotton and satin). There was also ridge detail on polycotton (grade 2, depletions one – five) and satin (grade 2 for depletions one – three and grade 4 at depletion four). The CAF again only had positive marks on the nylon swatches for all the donors, though none contained ridge detail.

9.2.4 Day 28

This was the least successful of all the days having no marks with ninhydrin or dry DFO and only one empty mark for donor one on nylon. However, there was some success with the fluorescent powder where donor one had marks on nylon (depletions one – five) and ridge detail on polycotton (grade 2 for depletions one – three and grade 1 for depletions four – five). Again the corresponding CAF samples only had marks on the nylon samples and once more there was no ridge detail.

As ninhydrin can develop further with time all the samples, for all the timelines, were stored and reviewed after one week and one month to see if extra detail or Ruhemann's purple had developed. However, though some of the samples appeared to be more purple in colour no extra detail was observed.

9.3 Statistical analysis of SPR, ninhydrin, dry DFO and fluorescent powder and their effectiveness in fingermark visualisation.

The Kruskal-Wallis test was used to determine the effectiveness of various fingermark development techniques (SPR, ninhydrin, dry DFO and fluorescent powders) in visualising fingermarks on five different fabrics (nylon, nylon-Lycra, silk, polycotton and satin). The null hypothesis (H_0) is no difference between the visualisation techniques of SPR, ninhydrin, dry DFO or fluorescent powders, and the alternative hypotheis (H_A) is that there is a difference between the techniques.

The majority of the samples in this study were not positive and did not allow the visualisation of marks or detail and this is reinforced by the results of the Kruskal-Wallis test [Table 9.1]. Here it can be seen that all the p-values were equal to or higher than 0.05, therefore in each case the H_0 should be accepted and the H_A rejected meaning that there is not a difference between the different techniques used to visualise the marks.

With nylon, there was some difference between the techniques used to visualise marks as illustrated by the mean rank values for SPR and fluorescent powder (28.50), ninhydrin (22.50) and dry DFO (18.50). Thus, it could be determined that of the four techniques used, SPR and the fluorescent powders are more successful in visualising marks, whereas the dry DFO is the least successful. The conclusion that the techniques are all similar in their limited ability to visualise detail is reinforced by the p-value of 0.050, and therefore that H_0 should be accepted.

Considering fabrics, the values for the nylon-Lycra samples show there was no difference between the techniques as they all had the same mean rank value of 24.50 and a p-value of 1.000 indicating this also, thus the H_0 should once again be accepted. However, polyester showed some detail with the ninhydrin (27.50), while all the other techniques were the same (23.50), thus the p-value was significantly high at 0.105. Silk had the same p-value of 0.105 but this time the fluorescent powder (27.50) visualised the marks, while the other techniques all had a mean rank value of 23.50. While polycotton had the same mean rank values for SPR and the dry DFO (22.00) ninhydrin and the fluorescent powder were higher (27.75 and 27.25), but overall there was little difference so the p-value of 0.106 meaning the H_0 should be accepted. The final fabric, satin, had the same mean rank value of 24.00 and a p-value of 0.392, indicating that the techniques were not different in this instance and the H_0 should be accepted.

Table 9.1: The Kruskal-Wallis tests carried out on the six fabrics involved in the depletion series study of SPR, ninhydrin, dry DFO and fluorescent powder. Data shown includes the number of samples, mean rank, Kruskal-Wallis value, degrees of freedom and p- value.

Nylon	Number of samples	Mean Rank	Kruskal-Wallis Value	Degrees of Freedom	p-value
SPR	12	28.50	7.833	3	0.050
Ninhydrin	12	22.50			
Dry DFO	12	18.50			
Fluorescent powder	12	28.50			
Nylon-Lycra					
SPR	12	24.50	0.000	3	1.000
Ninhydrin	12	24.50			
Dry DFO	12	24.50			
Fluorescent powder	12	24.50			
Polyester					
SPR	12	23.50	6.130	3	0.105
Ninhydrin	12	27.50			
Dry DFO	12	23.50			
Fluorescent powder	12	23.50			
Silk					
SPR	12	23.50	6.130	3	0.105
Ninhydrin	12	23.50			
Dry DFO	12	23.50			
Fluorescent powder	12	27.50			
Polycotton					
SPR	12	22.00	6.127	3	0.106
Ninhydrin	12	27.75			
Dry DFO	12	22.00			
Fluorescent powder	12	27.25			
Satin					
SPR	12	24.00	3.000	3	0.392
Ninhydrin	12	24.00			
Dry DFO	12	24.00			
Fluorescent powder	12	26.00			

9.4 Conclusion

The majority of results were poor as illustrated by the Kruskal-Wallis test results and that for all the techniques studied 78 % of the swatches were graded as 0, while only 20 % were rated as 1, 1 % graded as 2, 0.2 % as 3 and 0.2 % as 4. A comparison of the different types of DFO and ninhydrin was performed but the visualisation of marks using these techniques was also unsuccessful showing that neither technique is suitable for visualising marks on fabrics. Potentially the use of fluorescent powder is worth investigating further, especially due its success on feathers (McMorris, H. 2012 pers. comm., 12 April) which could be considered comparable to fabrics. This, however, is an extremely messy process and probably not practical for operational work.

10. COLD CASE STUDY

10.1 Aim

To use vacuum metal deposition (VMD) and cyanoacrylate fuming (CAF) to determine the level of fingermark and palm ridge detail from fifteen donors that can be visualised on cotton, nylon, polycotton and polyester samples aged over 2.5 years old.

10.2 Background

Many assault cases are reported relatively quickly after the event and as commented, reported that "the majority of reports to the police were made within 24 hours" (Kelly, Lovett and Child 2005), while Feist et al. (2007) stated that about half of the cases were reported on the same day and just under a third after over a week. Some cases though quickly reported and brought to Police attention are not solved or the investigation comes to a natural halt after all avenues of investigation are exhausted. These result in "cold cases" where evidence is put into storage and the case closed but the case can be reopened if new technologies are developed or new evidence comes to light. With that in mind this mini study aimed to simulate a cold case where evidence has either not been examined for fingermarks during the initial investigation or where no marks were found using other techniques.

10.3 Results and discussion

Samples of cotton, nylon, polycotton and polyester ranging from 2.8 – 4.2 years old were processed using standard operating procedures (SOP) for VMD (gold + zinc) and CAF. The samples to be processed using VMD or CAF were collected at the same time and stored at room temperature in plastic wallets, therefore the fabric samples are approximately the same age for VMD and CAF processing.

Cotton [Figure 10.1, Table 10.1] did not allow the visualisation of any marks using CAF and only 1 for VMD. The only positive result (9 %) for the VMD was from donor twenty (classed as a good donor) and was only a single fingermark impression. With the VMD cotton samples there were also several with possible target areas – donors two, six, seven, nine and ten, but all were empty marks and none of them contained any ridge detail. These results were not unexpected when comparing to results from previous studies on younger marks in which few cotton samples allowed the visualisation of areas of contact let alone ridge detail. It was hypothesised that the surface of the cotton allows the residues to evaporate or soak into the fabric surface; therefore are not available for either the VMD metals or cyanoacrylate (CA) during fuming to visualise any marks.

Table 10.1: VMD and CAF grading for donors 1, 2, 5-12, 15, 16 and 20 on cotton, nylon, polycotton and polyester fabrics. Grey squares indicate where a sample was not collected.

	Cotton		Nylon		Polycotton		Polyester	
Donor	VMD	CAF	VMD	CAF	VMD	CAF	VMD	CAF
1	0	0	0	1	1	0	2	0
2	0	0	2	1	1	0	2	0
5			0	1	0	0	1	0
6	0	0	1	1	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	0	1	0	0	0	0	0
9	0	0	0	1			0	0
10	0	0	1	1	0	0	1	0
11	0	0	2	1	0	0		
12	0	0	0	0			0	0
15			0	1				
16	0	0	1	1	0	0	0	0
20	1	0	1	1	0	0	0	0

Polycotton [Figure 10.1] did not allow visualisation of the CAF 2.84 year old samples and only two grade 1 marks on the VMD 2.83 year old samples in which both showed hand grabs with donor one being more obvious than donor two. Therefore these marks were only indications of where the fabric had been touched and could not be used to identify the donors due to lack of ridge detail. Of the positive samples the donors were classed as good and good to medium from past studies. In past studies, polycotton, like cotton, did not allow much visualisation of ridge detail, palmar flexion creases or grab marks, therefore to see marks on samples of such an age there would be an expectation that they would be from good donor donations.

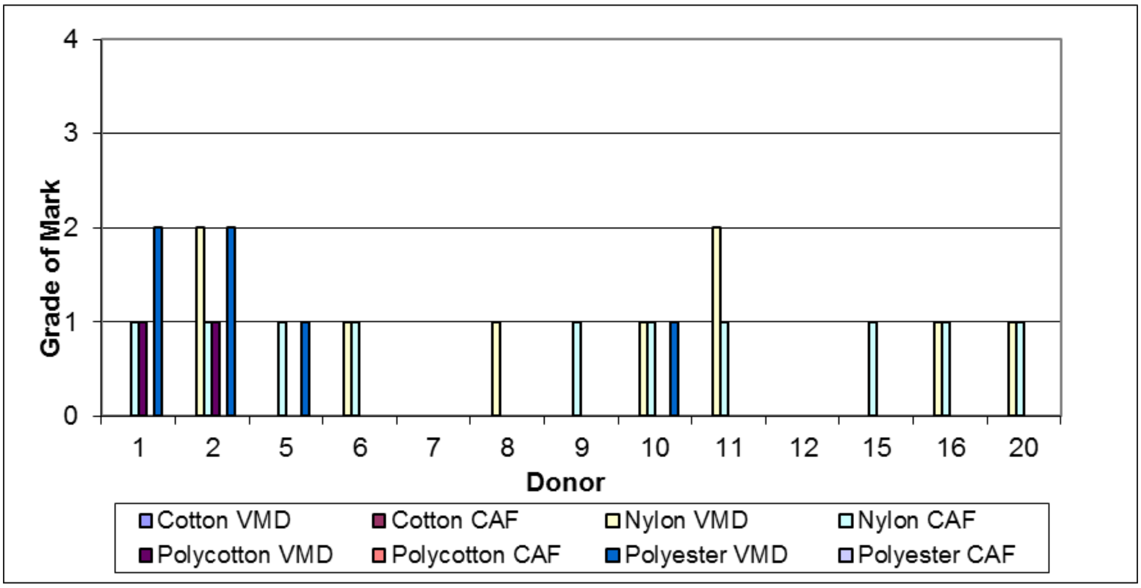


Figure 10.1: Combined grading for all fabric types (cotton, nylon, polycotton and polyester) of "Cold case" samples visualised with VMD and CAF. Samples range in age from 2.8 to 4.2 years old.

Polyester was negative for all CAF samples. VMD did however have more positive polyester samples (five) compared to the VMD polycotton samples (only two positive samples). Polyester had grade 2 for donors one and two, with grade 1 for donors five, ten and twenty. Additionally polyester had two other samples that had possible target areas (donor six and sixteen). The positive samples were from donors classed as good to medium, with the exception of donor ten who was classed as poor. The marks graded as 1 visualised on polyester were again not useful for identification, however could be targeted for DNA. The marks graded as 2 could possibly aid in identification due to the palmar flexion creases that have been visualised. Thus, overall, the combination of visualised marks and targeting for DNA could help in the identification of the person that has touched this fabric.

Nylon had the most positive samples for both VMD (7/13; 54 %) and CAF (10/13; 77 %) and even those classed as negative had possible target areas, raising the percentages to 70 % for VMD and 85 % for CAF. The visualised marks ranged from grabs with palmar flexion creases to possible fingermarks which may aid in direct identification or via DNA swabbing.

What comparing the techniques to each other [Figure 10.2] VMD seems to be more effective than CAF with 15/45 samples having positive marks and a further 8 of possible marks compared to CAF with 10/45 positive marks and 1 possible mark. As already discussed the majority of marks were empty grade 1 marks with no ridge detail. It was the VMD samples that had all of the highest grades of 2, all with palmar flexion creases (2 on polyester and 2 on nylon). Thus, this detail combined with the number of positive marks visualised with VMD (15 compared to 10 CAF samples) reinforces the opinion that VMD is more effective than CAF in visualising detail. However it must be said that the 10 positive marks for CAF were all on the same fabric (nylon), so CAF performed better on this fabric than VMD. VMD had three less samples than CAF with 7 positive marks, though two of these were graded as 2, whereas all the CAF samples were 1. Therefore, even though CAF visualised more positive samples these marks did not contain much detail, if any, and as VMD had higher values it can be considered to be more effective overall.

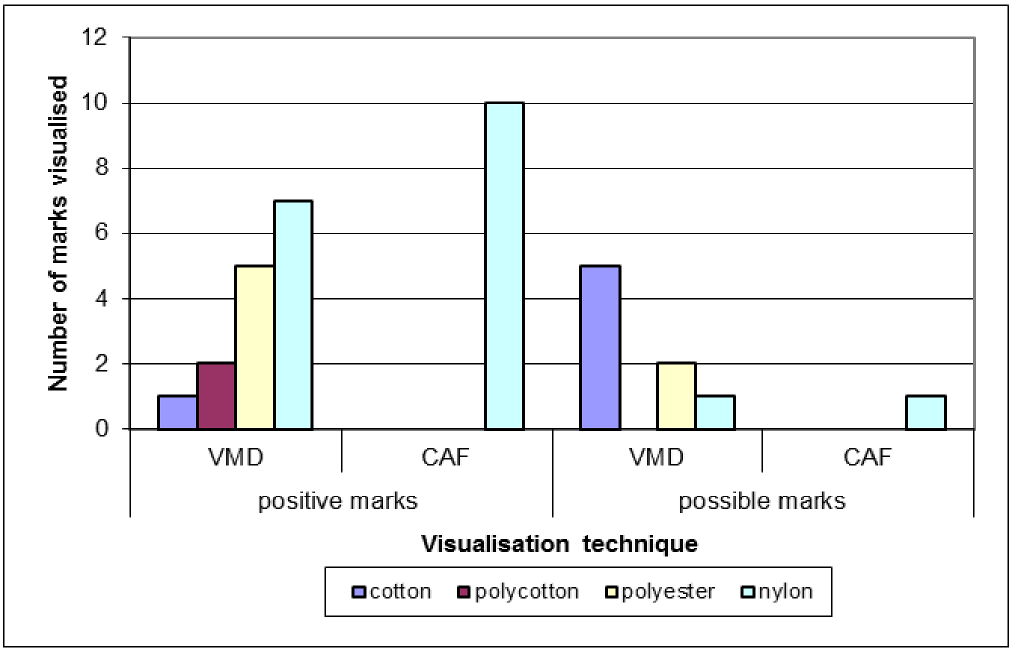


Figure 10.2: Number of VMD and CAF visualised "Cold case" samples displaying positive and possible marks visualised on all fabrics (cotton, polycotton, polyester and nylon).

Though not all of these cold case samples exhibited as many marks as younger samples (maximum age of 28 days in all other studies) with only 23 out of 90 samples (26 %) showing grades above 0, these results do follow the trends of previous studies. Rougher fabrics, such as cotton, allowed visualisation of fewer marks while smoother tighter weave fabrics, such as nylon allowed more marks and more ridge detail to be observed. Thus, evidence that was not investigated for fingermarks at the time of initial investigation or evidence from old unsolved cases could be examined later with the possibility of visualisation. This may not lead to identification through ridge detail but it may help investigator target areas to swab for DNA or allow the sequence of events to be determined or confirmed.

10.4 Statistical analysis of VMD and CAF visualisation of fingermark visualisation on fabric samples where the samples are between 2.8 and 4.5 years old.

Table 10.2: Mann-Whitney U test for the four fabric samples aged between 2.8 and 4.2 years old with planted grab marks processed with either VMD or CAF. Details include number of samples, mean rank, sum of ranks, Mann-Whitney U value and p-value.

	Number of samples	Mean Rank	Sum of Ranks	Mann-Whitney U value	p-value
All Fabrics					
VMD	44	48.36	2128.00	798.000	0.064
CAF	44	40.64	1788.00		
Cotton					
VMD	11	12.00	132.00	55.000	0.317
CAF	11	11.00	121.00		
Polycotton					
VMD	11	12.50	137.50	49.500	0.147
CAF	11	10.50	115.00		
Polyester					
VMD	11	14.00	154.00	33.000	0.014
CAF	11	9.00	99.00		
Nylon					
VMD	11	11.73	129.00	58.000	0.851
CAF	11	11.27	124.00		

The Mann-Whitney U test [Table 10.2] illustrates which technique – VMD or CAF is more suitable and effective at visualising fingermarks on the fabrics (cotton, polycotton, polyester and nylon) over 2 years old. The null hypothesis (H_0) is therefore no difference between the VMD or CAF visualisation techniques, and the alternative hypotheis (H_A) is that there is a difference between the techniques.

With all the fabrics combined VMD had the higher mean rank (48.36) and sum of ranks (2128.00) compared to CAF which had a mean rank of 40.64 and sum of ranks of 1788.00. Therefore, overall VMD is the more suitable and effective technique than CAF for the visualisation of fingermarks. The overall p-value was 0.064, which means there is a significant difference and that the H_0 should accepted and the H_A rejected.

When looking at each fabric separately it can be seen that VMD was the technique of choice for each fabric in the study, though with some fabrics the difference is not as significant. Cotton showed a mean rank of 12.00 and sum of ranks of 132.00 with VMD, whereas the CAF values were lower with a mean rank of 11.00 and a sum of ranks of 121.00. The p-value with cotton was 0.317, which means there is a not a significant difference and the H_0 should be accepted and the H_A rejected. Polycotton showed similar values of 12.50 for the mean rank, 137.50 for the sum of ranks with VMD, while with CAF the mean rank value was 10.50 and the sum of means was 115.00. These values led to the p-value of 0.147, thus the H_0 should again be accepted and the H_A rejected. These fabrics did not allow much detail from either technique and in most cases, it was just marks indicating the fabric had been touched and therefore this would explain why there is not as big a difference in the values from the Mann-Whitney U tests. Polyester showed a bigger difference between the VMD and CAF values, with the mean rank values of 14.00 for VMD and 9.00 for CAF samples as well as sum of ranks of 154.00 (VMD) and 99.00 (CAF). The overall p-value was 0.014, thus this time the H_A should be accepted indicating that there is a difference between the two techniques. The final fabric tested was nylon, and these samples resulted in mean rank values of 11.73 for the VMD processed samples and 11.27 for the CAF treated samples. The sum of ranks means were also extremely similar with 129.00 for VMD and 124.00 for CAF. These values all resulted in a p-value of 0.851, which is significantly high and therefore would lead to the H_0 being accepted. Therefore, in each case the Mann-Whitney U values illustrate that the VMD technique is the one that is most effective at visualising marks on these fabrics. However, three out of the four fabrics (nylon, cotton and polycotton) had significance values that are quite high indicating that there is not a significant difference between how much detail was visualised using the two techniques.

To reinforce the information determined by the Mann-Whitney U test and to determine which fabric visualised the most detail, a Kruskal-Wallis test [Table 10.3] was also carried out. In this case the H_0 is that there is no difference between the fabrics, and the H_A is that there is a difference between the fabrics. The results for VMD showed that there was indeed a difference between the four fabrics as the p-value was 0.023 which means there is a significant difference between the fabrics tested and therefore the H_A should be accepted and the H_0 rejected. The fabrics could also be ranked in order of the detail visualised. Nylon had the highest rank number (29.09), followed by polyester (25.45), polycotton (18.64) and cotton (16.82) with the lowest number. With CAF, there was only one fabric that had a value different from the other – nylon had a mean rank of 34.50, whereas all the other fabrics (cotton, polyester and polycotton) had the mean rank of 18.50. Therefore nylon was the only fabric to show any detail, which is reinforced by the p-value of <0.001, therefore, here the H_0 should be rejected and the H_A accepted, as there is a difference between nylon and the rest of the fabrics.

Table 10.3: Kruskal-Wallis test of the four fabrics aged 2.8 to 4.2 years with planted latent grabs which were visualised with either VMD or CAF. The table includes details of sample number, mean rank, Kruskal-Wallis value, degrees of freedom and asymptotic significance value.

	Number of samples	Mean Rank	Kruskal-Wallis value	p-value
VMD				
Cotton	11	16.82	9.496	0.023
Polycotton	11	18.64		
Polyester	11	25.45		
Nylon	11	29.09		
CAF				
Cotton	11	18.50	28.667	0.000
Polycotton	11	18.50		
Polyester	11	18.50		
Nylon	11	34.50		

Overall, with the information gleaned from the other studies reported in this thesis, the order determined here with the VMD and, in part by the CAF, was not unexpected as this has been found in earlier work reported in this thesis and follows the hypothesis that more detail is visualised on smoother tighter weave fabrics. It was also determined, in the other studies that VMD was more effective than CAF in visualising finger ridge detail and marks, which has also been confirmed here. Therefore, both the Kruskal-Wallis and Mann-Whitney U tests, confirm the expected results that VMD visualises more detail then CAF and, of the four fabrics tested in this cold case section, nylon allows the visualisation of the most detail.

11. COLLABORATIVE WORK

11.1 Optimising touch deoxyribonucleic acid (tDNA) recovery and analysis from fabrics and clothing

11.1.1 Aim

To determine whether VMD has an effect on the recovery of tDNA from fabric.

11.1.2 Background

Touch deoxyribonucleic acid (tDNA) can be found when a person touches or picks up an item and even though approximately 400,000 epithelial cells shed per day by humans are keratinised thus do not contain a nuclei they do contain fragmented DNA. Thus this, along with sweat containing free nucleic acid, contributes to tDNA being a useful source of DNA profiles (Ryan 2012). Many studies have been carried out, dating as far back as Pesaresi et al. (2003), to determine if DNA can be successfully collected from items used in crimes. Also, more recently, the amount of DNA that can be collected from fabric, glass and wood items, which had been held for 60 seconds (Daly, Murphy and McDermott 2012) as well as cotton and plastic items which donors rubbed on their hands for 15 seconds (Goray et al. 2010) has been reported. Both of these studies showed that small quantities of DNA (1.23 ng for the fabric in the Daly, Murphy and McDermott (2012) study and 11.68 ng for the Goray (2010) study could be recovered from these short contacts. These are extremely small quantities, however with the use of the polymerase chain reaction (PCR) these small quantities can be replicated and thus the possibility of a profile being obtained increased to 23 % of the time in the case of the Daly, Murphy and McDermott (2012) study.

The amount of DNA that may be recovered is dependent on several factors, such as the type of contact; the substrate contacted as well as the person themselves. Goray et al. (2010) showed that increased pressure and friction led to an increase in transfer of DNA, so if increased friction increases transfer it is only logical that a rougher substrate will also lead to increased DNA retention. The individual involved in the contact also impacts on the amount of transfer – washing reduces DNA on an individual's hands; Wickenheiser (1999) noted that individuals who touch their faces and hair, thus load their hands with extra DNA. While the amount a person sweats can also increase the available DNA – Wickenheiser (1999) suggested it is the sweat moving through the pores, thus picking up cells and therefore DNA on the way or that the sweat contains cell-free nucleic acids and epithelial cells, both of which contain DNA (Quinones and Daniel 2012). How long this DNA stays on the substrates has only been studied to a small extent. Raymond et al. (2009) found that after 2 weeks there was a significant reduction of recoverable DNA on gloss painted window sills and vinyl surfaces, however when testing old case samples they found that DNA was recovered from a laptop 62 days after the crime and 55 days from a bag involved in a drugs case. More interestingly for this thesis, is the work carried out by Linacre et al. in 2010 where cotton, nylon and polyester were rubbed by donors between their thumb and forefinger for 5 seconds. The samples were then placed on a sunlit windowsill after which direct amplification was carried out up to 36 days later and full, as well as "near complete profiles" were obtained.

Therefore, to determine the best operational parameters, fabric samples were treated with vacuum metal deposition (VMD) to allow the area grabbed by an individual to be visualised and targeted for DNA, which could then be extracted and analysed. During an assault, which is what the deposition of the grab marks is simulating, there will be interaction between the assailant and victim in the form of hitting, pushing, grabbing and so on, which in turn will result in an exchange of DNA as well as fingermarks and hand marks being left. However, the marks left on the individual and their clothing, unless blood marks, will be latent marks so need to be visualised and then the marks may aid in the determination of the sequence of events and an identification, as well as showing where the article should be taped or swabbed for tDNA.

Many techniques can be used to visualise latent fingermarks, such as fingerprint powders, VMD, ninhydrin, 1, 8-diaza-9-fluorenone (DFO) and cyanoacrylate fuming (CAF) with basic yellow 40 (BY40) and many studies have been carried out as to whether there is an impact on DNA recovery when performing these techniques prior to DNA collection.

Stein, Kyeck and Henssge (1996) used blood and saliva stains on various substrates and visualisation techniques to determine their effect on the DNA recovered. They studied the use of: CAF on razor blades and plastic foils; carbon fingerprint powder on glass slides; gentian violet on the sticky side of adhesive tape; and ninhydrin on paper. They found that the chemicals used in the visualisation processes did not have a detrimental effect on the DNA extraction, quality, and typing, therefore stated that fingerprinting could be carried out before DNA collection without damaging the DNA. Zamir, Springer and Glattstein (2000) employed adhesive tape to investigate the recovery of DNA from fingermarks visualised using the techniques CAF/BY40 and crystal violet staining. Though there were a reduced number of loci obtained, profiles were obtained from all but one of the donors; again illustrating that fingermark enhancement could be carried out prior to DNA collection. A more recent report by Bhoelai et al. (2011) utilising paper and plastics found that VMD and CAF still allowed successful short tandem repeat (STR) profiling afterward, however BY40 and other techniques that involved dyeing via washing reduced DNA recovery.

DFO and ninhydrin are also popular fingerprinting techniques and are generally used on porous substrates such as paper. Zamir, Oz and Geller (2000) investigated DFO, while Schulz et al. (2004) studied ninhydrin and Sewell et al. (2008) investigated both techniques. They all found that DNA could successfully be collected from all the paper-based substrates examined. Zamir, Oz and Geller (2000, p. 446) noted that while DFO was considered to "be a destructive reagent in DNA profiling" they were still able to obtain DNA profiles by using STR analysis. Schulz et al. (2004) used wallpaper from a criminal case and thought the DNA recovered turned out to be from the mother's partner, as well as another individual, possibly a friend and not the assailant. Although, this did not help in the case itself it demonstrated that ninhydrin did not interfere with DNA recovery. The same could be seen in the Sewell et al. (2008) study, where they found that the available DNA was decreased due to the paper type, especially the office paper and card and not due to the fingerprinting techniques. Schulz et al. (2004) found that amplification was not compromised to a great level, therefore profiles were obtained and Bhoelai (2011) found the same, but that ninhydrin and DFO may cause DNA contamination.

von Wurmb, Meissner and Wegener (2001) and Bille et al. (2009) investigated the use of CAF on glass slides and pipe bombs respectively. Though von Wurmb, Meissner and Wegener (2001) were testing saliva and not fingermarks it is the effect of CAF on DNA recovery that is of interest and here they found that both extraction methods (Chelex method and an Invisorb Forensic kit) allowed extraction and therefore amplification and DNA profiles. They did find however, that the Chelex CAF treated samples were sometimes 60 % lower than the controls or even did not allow complete amplification. On the other hand, the Invisorb method, though more time consuming, produced a more effective amplification. They also stated that there was an added benefit to using CAF in that the saliva stains were more visible and fixed into position, thus easier to target for extraction. The Bille, Cromartie and Farr (2009) study measured amounts of DNA, in the form of a cell suspension, added to areas on pipe bombs, which were then deflagrated, the pieces collected, CAF performed and the visualised areas swabbed. There was a significant loss of DNA from what was planted, up to 90 % after a 3 month delay between blast and collection, but they decided that CAF did not have "a measurable effect" on DNA being collected and processed. Shalhoub et al. (2008) reported on the use of DNA collection after CAF processing of fingermarks that had been deposited on several substrates such as a drinks can, plastic bottle, waxed paper cup, glass light bulb, £2 coin and plastic mobile phone case. Isomark™, a casting material, was then coated over the marks, left for 24 hours, recovered then both the cast material and the substrate were treated with CAF, before being swabbed for DNA. Overall, the CAF made the marks easier to see on the Isomark™ but there was little difference between the quality of marks visualised with the casting material and on the surface of the coin, bottle, mobile case or cup, however the casting material was found to have poor and unclear detail on the cup and mobile case. Thus, Isomark™ was more successful at recovering fingermark detail from non-porous substrates and that more DNA was recovered from the non-porous smooth substrates, such as the aluminium can. Approximately 42 % of the substrates tested gave enough DNA to be profiled and 82 % of these gave full profiles.

Less work seems to have been carried on as to the effect of DNA recovery after metal deposition to visualise fingermarks. The paper by Lowe et al. (2003) and oral presentation by Murray et al. (no date) based on the same work examined several enhancement techniques and found that DNA profiles could be obtained between 33 % and 100 % of the time, depending on the technique and when the DNA was collected. In the case of metal deposition, 100 % donor profile was recovered from a freshly enhanced mark compared to 0 % from one that had been left for 100 days. They found that more DNA was recovered from marks on non-porous substrates and generally more DNA was collected from fresher marks, with the exception of vacuum CAF (a technique used out with the UK) which actually increased from 49 % from the freshly enhanced mark to 86 % on the 100 day old enhanced mark.

While all these studies show there was some effect on the amount, they all allowed DNA to be recovered and profiles obtained and in some cases the visualisation technique "fixed" the DNA in place and made it more obvious to find and thus collect. Therefore, the current study carried out in conjunction with Ignacio Quinones Garcia aimed to determine what effect, if any, that gold + zinc VMD had on whether it was possible to recover sufficient DNA from finger marks on fabrics to produce a profile.

11.1.3 tDNA recovery from fabrics

The identification of an assailant in assault cases comes from the testimonies of the victims and eyewitnesses as well as other evidence, such as fingermarks and tDNA. During an assault the individuals and their clothing will be pulled, grabbed and damaged, so there is most likely a transfer of DNA from one individual to the other and their clothing. In order to simulate this scenario, fabric samples and items of clothing were grabbed and then processed with VMD to visualise marks and DNA collected. The fabrics, studied in this section, were all in common use for modern day clothing, and included: 100 % nylon swatches, 100 % cotton T-shirts and a 100 % polyester chemise, which might be seen in assault cases, and, hence, in forensic laboratories.

Generally, to collect DNA from clothing the item is taped with adhesive tape over the areas that are thought to have been touched, until the tape has reduced in tackiness due to fibres and cellular material coating its surface. The tape may then be swabbed with xylene to increase extraction efficiency. However, due to the loss of cell free nucleic acids by the possibility of them being soaked into the fabrics (Linacre 2010) direct amplification was also carried out in an attempt to collect as much material as possible.

Therefore, this study will aim to determine what effect VMD has on the recovery of tDNA from fabric and clothing collected during simulated violent crimes, as well as which method of DNA collection is best to recover the highest quantity of tDNA.

11.1.4 Effect of VMD on tDNA recovery and profiling on nylon samples

Day 6 nylon samples from nine of the donors (two, five, six, nine, eleven, thirteen, fifteen, sixteen and twenty) used in the study were sent for DNA analysis (Quinones Garcia, I. 2011. pers. comm., 11 May; Quinones Garcia 2011), along with untreated control swatches and DNA buccal swabs. These swatches contained marks [Table 11.1 and Figure 11.1], though some in the case of donor two and five were good, none were excellent, therefore less likely to lead to an identification from ridge detail. However, even though creases are sometimes observed on fabric and clothing from grabs after VMD it is more obvious where the fabric has been touched, thus the collection of DNA should be easier.

Figure 11.1: Day 1 nylon grabs processed with VMD displaying varying levels of detail. (A) donor twenty with partial ridge detail in finger 1; (B) donor two with palmar flexion creases, but empty marks, therefore no ridge detail; and (C) donor fifteen with no ridge detail, only faint fingertip and thumb marks. (Samples sent to Ignacio Quinones Garcia for DNA profiling, to determine effect of VMD on DNA collection).

Table 11.1: Ridge detail (grades and descriptions) visualised with VMD on nylon samples for donors 2, 5, 6, 9, 11, 13, 15, 16 and 20. Samples then sent to Ignacio Quinones Garcia for DNA profiling.

Donor	Ridge grade	Detail description
2	Fair (2)	Grab – palm lines, empty marks
5	Good (3)	Grab – some palm lines (40 %) and ridge detail on finger 3 (other marks dark)
6	Fair (2)	Grab – very little palm, faint ridge detail on finger 2
9	Empty (1)	Grab – not much palm or fingers 3 and 4
11	Fair (2)	Target area - palm lines and empty marks
13	Empty (1)	Finger impressions and small area of palm
15	Fair (2)	Partial grab – thumb and fingers 1 (including ridge detail), 2 and tip of 4
16	Fair (2)	Grab – light and dark areas, palm lines (50 %)
20	Empty (1)	Thumb and fingertip impressions

To collect the DNA, sections were cut from the grab marks visualised by the VMD process. The VMD treated untouched controls and the untreated samples both had 12 x 8 cm sections cut from their centres, as it was expected that the donor would have touched this area. These were then cut into 2 cm^2 sections and dried blood spot protocol extraction carried out with a QIAgen QIAamp® DNA Mini extraction kit.

Table 11.2: NGM chemistry-processed DNA profile results of VMD treated grabs on nylon swatches and untreated nylon swatches containing grabs.

Donor	VMD Treated Samples		Untreated Samples	
	Alleles	Dropin	Alleles	Dropin
2	31	11	32	11
	27	2	31	12
5	28	10	21	10
	24	6	22	7
6	32	7	25	9
	12	2	21	20
9	14	9	4	0
	0	0	14	8
11	29	7	22	15
	32	0	31	15
13	32	13	20	9
	28	11	11	11
15	18	20	19	19
	12	2	30	14
16	32	1	32	1
	31	1	30	12
20	32	5	32	12
	12	3	31	13
Average	25	7	23	11

From Table 11.2 and the data in appendix 16.1 [Table 16.1 – 16.9] it can be seen that the treated samples produced an average of 25 true alleles (full profile 78 % of the time) whereas with the untreated samples an average of 23 true alleles were obtained (full profiles 72 % of the time). Thus, there appears to be no interference from the VMD in the polymerase chain reaction (PCR) process and that the VMD actually aided in the process by visualising where to collect the DNA. Therefore, it could be considered that there was a correlation between how well the mark was developed and quantity of DNA – the higher the detail visualised the more DNA was collected, thus a higher chance of a profile.

11.1.5 Effect of VMD on tDNA recovery and profiling on items of clothing

To make the study more realistic and relevant to operational cases, 100 % cotton T-shirts and 100 % polyester chemises were examined. The items were grabbed by the donors (five, thirteen and twenty) to simulate an attack, enhanced with VMD [Figure 11.2] and then taped twice. The DNA was then extracted from the tape using a QIAGen Mini spin column and 50 µL elution recovered.

After VMD the T-shirts and chemise showed few marks and no ridge detail [Figure 11.2] – though on the T-shirts: donor five had a faint grab with outlines of the fingers, thumb with some of the palm; donor thirteen had a very faint grab; finally, donor twenty had no palm, only finger and thumb tip outlines [Figure 11.2].

Table 11.3: Results detailing amount (ng) of DNA collected and number alleles amplified using SGM Plus and NGM chemistries from samples taken from VMD-processed satin polyester chemises and cotton T-shirts.

DNA Collection Method	Donor	DNA collected (ng)	Number of Alleles Amplified	
			SGM Plus	NGM
Polyester Chemise				
Taping	5	21.5	22	32
	13	4.5	18	32
	20	8	22	22
High Volume Extraction	5	0	0	0
	13	0	0	0
	20	0	0	0
Cotton T-shirts				
Taping	5	0	0	0
	13	1	0	0
	20	1	1	4
High Volume Extraction	5	0	0	0
	13	0.25	0	0
	20	0.1	0	0

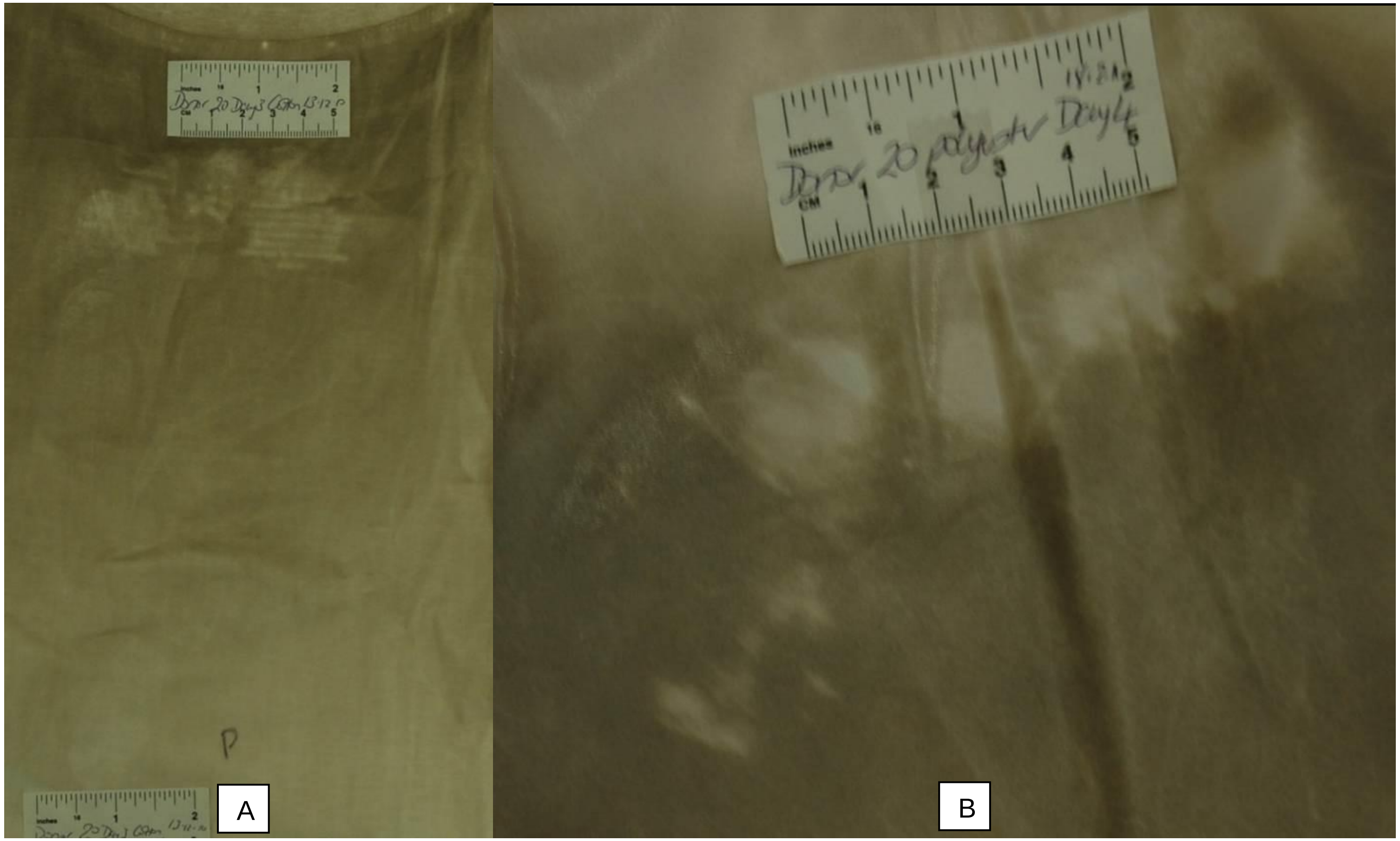


Figure 11.2: VMD-processed samples of clothing displaying faint grab marks from donor twenty. (A) 100 % cotton T-shirts and (B) 100 % satin polyester chemise. Samples sent to Ignacio Quinones Garcia for DNA profiling, to determine effect of VMD on DNA collection.

Operationally the T-shirt was more difficult to attach to the VMD cradle and had to be folded to fit, therefore making it thicker than the previously used samples. Compared to the swatch samples it also took much longer (approximately half an hour) to evacuate the chamber in the presence of the T-shirts and the vacuum fluctuated most likely due to the size of the sample and heavier T-shirt cotton that was used. This increased time to pump down (up to two hours) agrees with the work of Collins, Cole and Stroud (1973) during their Atomic Weapons Research Establishment (AWRE) trials using worn items of clothing. The lack of ridge detail, but definite target areas obtained on the T-shirts in the current work was similar to that found on cotton sheeting or shirt material in the Collins, Cole and Stroud (1973) study. With the polyester chemises donor five only left a faint grab, however this time there was also some palmar flexion creases (approximately 20 %). There may have been more detail visualised had the article been completely flush to the cradle, as this may have effected metal deposition, however this illustrates the possible problems that may occur with processing full items of clothing. Both donors thirteen and twenty only left empty fingermarks and no detail or any palmar flexion creases. The marks visualised with this satin weave polyester were not as detailed as with the corresponding samples, however this is most likely due to the article being larger and the metal deposition not being as effective. Of course, it may also be due to the donors who may not have had as many residues on their hands on the donation days, or, even, the fabric itself having a protective coating on the surface.

With the cotton T-shirts [Table 11.3], donor five gave no profile information for either taping or high volume extraction using Second generation multiplex (SGM) plus or Next generation multiplex (NGM) chemistries. Donor thirteen afforded 1 ng of DNA for taping, but no alleles for SGM plus or NGM and only 0.25 ng of DNA for high volume extraction with no alleles being amplified. Finally, donor twenty also resulted in 1 ng of DNA from taping and this led to 1 allele being amplified with SGM plus and 4 with NGM, while only 0.1 ng was collected from the high volume extraction method and this did not result in any alleles being amplified. The polyester results [Table 11.3] with the taping method were more successful, in that each donor (donor five 21.5 ng, thirteen 4.5 ng and donor twenty 8 ng) had much more DNA collected, which in turn, resulted in more alleles being amplified. For donor five, 22 alleles were amplified using SGM plus compared to 32 alleles using NGM; with donor thirteen there were 18 using SGM plus and 32 using NGM; and with donor twenty the results were 22 for SGM plus and 32 for NGM. However, the high volume extraction was unsuccessful entirely – no DNA extracted from the chemises and therefore no alleles amplified.

The cotton results did not produce as many alleles as the nylon samples and this may be due to the surface properties of the fabrics themselves – cotton is more absorbent than nylon, therefore the cell free nucleic DNA may have been absorbed into the fabric becoming harder to collect from the fibres during the extraction process. It could also be as simple as the fact that high volume extraction is more effective on different substrates than others. However the taping did give some positive results, therefore if further work was carried out on both techniques to optimise the processes they could be used in conjunction with VMD to produce a DNA profile and aid in identifications.

A Mann-Whitney U test was carried out to determine whether taping or high volume extraction was more effective at extracting DNA from two different clothing types (polyester satin chemise and cotton T-shirts). Thus, the null hypothesis (H_0) is no difference in the extraction techniques while the alternative hypotheis (H_A) is that there is a difference between the techniques.

Table 11.4: Mann-Whitney U test results for the two different techniques of DNA amplification collected via two different methods from two fabric articles visualised using VMD. Results show the number of samples in each fabric set, the mean rank of each fabric set, the sum of the ranks, the Mann-Whitney U value, degrees of freedom and p-value.

Fabric	Technique	Number	Mean Rank	Sum of Ranks	Mann-Whitney U Value	p-value
SGM Plus						
Satin	Taping	6	5.00	15.00	0.000	0.034
	High Volume Extraction	6	2.00	6.00		
Cotton	Taping	6	4.00	12.00	3.000	0.317
	High Volume Extraction	6	3.00	9.00		
NGM						
Satin	Taping	6	5.00	15.00	0.000	0.034
	High Volume Extraction	6	2.00	6.00		
Cotton	Taping	6	4.00	12.00	3.000	0.317
	High Volume Extraction	6	3.00	9.00		

When considering the data in Table 11.4, the H_A should be accepted and the H_0 rejected in the case of satin as the p-value is <0.05 (0.034) for both the SGM Plus and NGM. However, the cotton T-shirts all have a p-value of 0.317, thus the H_0 should be accepted as there is little difference between the two techniques.

The DNA extraction techniques can be seen as different in the case of both techniques for the satin as the mean rank and sum of ranks are high for satin compared to cotton. This is as expected when considering the high volume extraction method did not collect any alleles for amplification on either the polyester chemises or the cotton T-shirts [Table 11.3]. Therefore, it appears that in the case of these types of clothing that the taping method should be used to extract DNA, prior to amplification.

11.1.6 Direct PCR of polyester samples

Ten donors planted grabs on two separate polyester samples and then one was treated with VMD, while the other was untreated. Controls, including clean untouched and unprocessed samples as well as untouched samples treated with VMD were also processed. Direct PCR was carried out on all the samples using the Linacre et al. (2010) method of directly amplifying samples with NGM – duplicates of the treated samples had 2 cm x 2 cm sections removed, with irradiated scissors to reduce contamination, while the samples that were untreated had section removed from the areas thought to have been grabbed by the donors. The direct PCR method was used as the high volume extraction method had proved unsuccessful on several fabric types and the fact that the free nucleic acids may soak into the fabric, thus be unavailable for taping.

Table 11.5: Results detailing number of alleles amplified using NGM from polyester swatches that had been grabbed by the donor. The swatches treated with VMD to visualise the grab mark are compared to those left untreated.

	Alleles Amplified						
Samples	0 - 5	6 - 10	11 – 15	16 - 20	21 – 25	26 - 30	31 - 32
Treated	11	2	1	0	1	1	4
Untreated	18	2	0	0	0	0	0

The results for the VMD visualised samples proved to be more successful than the samples that had not undergone VMD [Table 11.5]. None of the untreated samples yielded a full profile and 90 % only had five NGM alleles successfully amplified, whereas four out of 20 (20 %) VMD treated samples resulted in a full DNA profile. Therefore it seems that VMD does not inhibit PCR and can be used to target areas to collect DNA from, which in turn could improve the chances of producing a full profile [Figure 11.3].

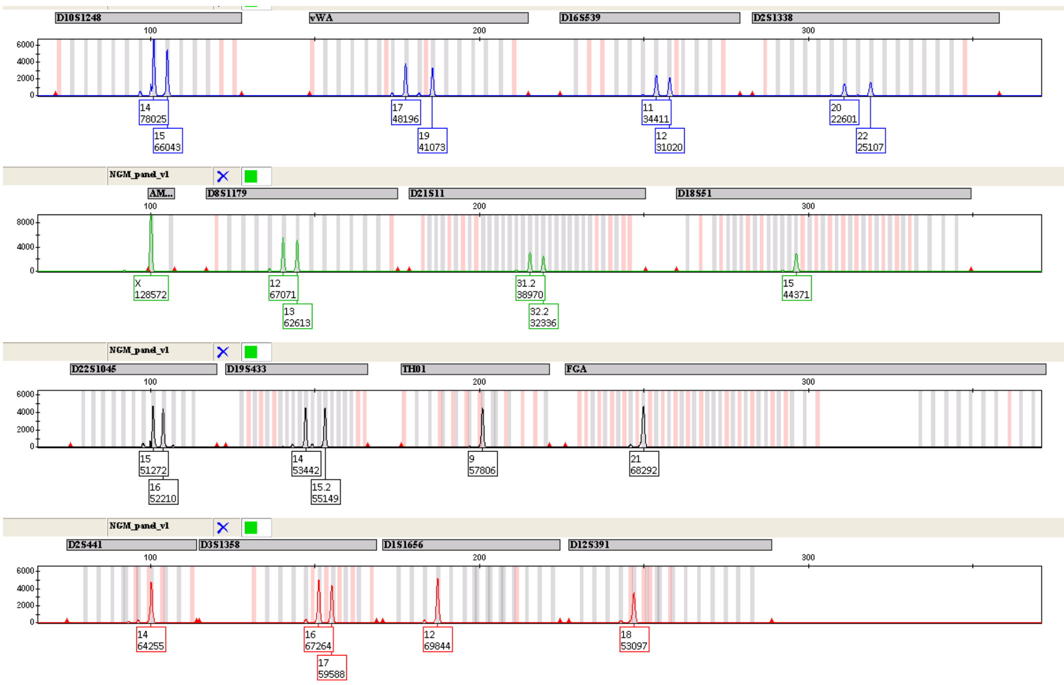


Figure 11.3: Example of high quality full NGM DNA profile obtained from a sample visualised with VMD (Quinones Garcia, I. 2011. pers. comm., 26 May; Quinones Garcia 2011).

The direct PCR process was also carried out using archived, 2007, VMD visualised samples from the same donors – again carried out in duplicate from sections cut from the visualised grab. These samples were used to imitate a cold case sample that of a piece of evidence that has been left unexamined or unsuccessfully examined for many years. The results were extremely low for these samples – only one sample produced a full profile, two produced partial profiles, while all the other samples produced no profiles. However, these samples were considerably older than any of the other samples examined, so it could be considered a success to be able to produce a DNA profile from 10 % of the samples (Quinones Garcia, I. 2011. pers. comm., 26 May; Quinones Garcia 2011).

11.1.7 <u>Overview of VMD on the recovery and profiling of DNA from fabrics and clothing</u>

VMD does not appear to interfere with DNA extraction and PCR, and hence the ability to obtain full and/or partial profiles. It also aids DNA recovery by indicating where an item has been touched, thus reducing the area of the article that needs to be taped, as well as unnecessary taping of areas that have not been touched and thus a reduction of contamination by mixed profiles. As well as helping locate tDNA the visualised marks can illustrate in some way what may have occurred during an incident, which coupled with the tDNA evidence, can add strength to the significance of the resulting evidence. Generally in case work the areas that would be taped would not be as high as the 50 % that was taped during this study and would be guided by information from witnesses and the victim themselves, therefore the marks visualised by VMD can only aid in this process by helping to pinpoint where the item should be taped.

There is always the possibility of contamination and secondary transfer during processing and this was found to be the case with some of the samples in this study, with overall percentages of 17 for the NGM profiles and 12 of the SGM profiles containing contaminating peaks (Quinones Garcia, I. 2012. pers. comm., 6 April; Quinones Garcia 2011). This is especially likely to occur in real-life cases as the victim will of course be wearing their clothing, thus their own DNA will be present. It should be noted that the negative controls in the study were clean, therefore the extra alleles most likely came from the donors or were present already on those fabrics, but not on the controls. Quinones Garcia also stated that "the number of contaminating alleles noted in untreated samples was slightly higher than in treated samples. This can suggest that by targeting relevant touched areas, contamination can be reduced, as DNA recovery from areas not touched by the volunteer are avoided, thus minimising contaminant deposits" (Quinones Garcia, I. 2012. pers. comm., 6 April).

Overall, VMD combined with DNA extraction and profiling seem to be a viable way of identifying an assailant in serious crimes – the combination of ridge detail as well as a DNA profile could help lead to the identification of those involved.

11.2 Blind Trial using Vacuum Metal Deposition (VMD) and Cyanoacrylate Fuming (CAF) on Fabric Swatches

11.2.1 Aim

To determine whether planted marks on various fabrics can be processed with VMD or CAF and correctly located by a fingermark expert.

11.2.2 Background

All the samples throughout this study were graded by the same person, who is not a fingermark expert, therefore it was decided to carry out blind trials where an operational fingermark expert from the Scottish Police Authority Forensic Services

(SPAFS) would process, grade and record any marks visualised. In so doing, the bias that may be in place due to the researcher collecting the samples and processing them was removed and the individual processing the samples would have to use their knowledge and expertise to evaluate whether the marks visualised were in fact fingermarks. The fingermark expert has over 20 years of experience in fingermark recovery and identification, working both in the field as well as in the laboratory. This experience covers all aspects of chemical and physical development of fingermarks, photography, as well as identification of fingermarks by comparing crime scene marks to 10 print cards.

11.2.3 Results and discussion

Two different blind trials were performed with silk, cotton and polycotton for the grid study and silk, rayon and polycotton for the grabs. The grid swatches had five marks planted in known areas by the researcher. The swatches were then processed and analysed by the fingermark expert and then compared to the location of the planted marks. In the grab study, two out of the three swatches had grabs planted by the researcher and then the swatches were processed and analysed by the expert.

With regards standardisation of the samples in this trial the expert followed the same procedure for VMD and CAF as well as using the same grading scale as the researcher.

For the grids [Table 11.6] it appears that VMD is more successful than CAF in visualising marks on the three fabrics used in the trial, as 34 out of 45 marks on the VMD samples were visualised, whereas only 14 out of 45 marks were visualised on the CAF samples. When considering the results from the other trials in this study it follows an expected pattern of smoother, tighter weave fabrics, in this case the silk, were visualised more and with better detail than rougher and or looser weave fabrics, such as the cotton and polycotton. However, while VMD visualised more marks, it was CAF that visualised more ridge detail, as can be seen by considering at each fabric individually.

Table 11.6: Grids for silk, cotton and polycotton for donor A, B and C (X indicates a fingermark or mark, while O indicates where a mark had been planted, but was not visualised)

	VMD									CAF								
Fabric	**silk**			**cotton**			**polycotton**			**silk**			**cotton**			**polycotton**		
Position	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
1	X	X	X			O							O	O			O	
2			X	X	X	O	X		X	X								
3		O					X				X	X			O			O
4								X							O	O		
5	X			X								X						
6											O			O	O		O	O
7		O						X		X		X	O		O	O		
8	X				X				X		X		O	O			O	
9			X	X				O		X		X		O				
10	X						X						O				O	O
11						O	X		X								O	
12		O			X			O	X		X		O			O		
13																		
14				X												O		O
15	X				X	O			X	X			O					
16			X		X	O		X			X	X						
17														O	O	O		
18		O	X	X			X			X								O

Silk VMD donor A was positive on all the planted grid boxes though all of these marks were empty with no ridge detail. It is thought that the reason why they were all empty was that the marks were too fresh – they had been planted on the same day they were processed therefore the rest of the samples were collected, then processed three days later. Silk VMD donor B was negative on four out of the five planted marks, with the fifth mark being graded as a possible mark, though would not be considered an empty mark and definitely did not contain any ridge detail. This donor was considered a poor donor in the other studies, therefore the lower number of positive marks compared to the other two donors was not unexpected. Donor C silk VMD was positive for all the planted marks, though again no ridge detail was seen and this was unexpected as C was considered a good donor in other studies. The lack of ridge detail may have been due to the marks being too fresh as previously discussed. Silk

CAF donor A mostly visualised scuff marks (marks that could not be identified as being from a fingermark) on square 2, 7, 9 and 15, as well as squares 5 and 8, though no mark had been planted here. This may have been due to contamination on the fabric or the donor touching these areas as they planted their other requested marks. This donor did however; leave a mark in square 18 that contained a visible pattern, though the ridge detail was poor it was enhanced further by use of fast Fourier transform (FFT) [Figure 11.4].

Silk CAF donor B had four positive marks, two on squares 3 and 8 with no ridge detail, two on squares 12 and 16 with poor ridge detail, and the fifth planted mark on square 6 was not visualised. Finally, silk CAF donor C had two false marked squares (squares 1 and 2) and one positive mark (square 16). Of the other planted marks, three contained varying levels of ridge detail: square 9 was poor, while square 5 and 7 both contained some detail. Both squares 5 and 7 contained visible patterns, though the ridge detail in square 7 was broken in areas, while in square 5 it was good and was enhanced further by use of FFT [Figure 11.5].

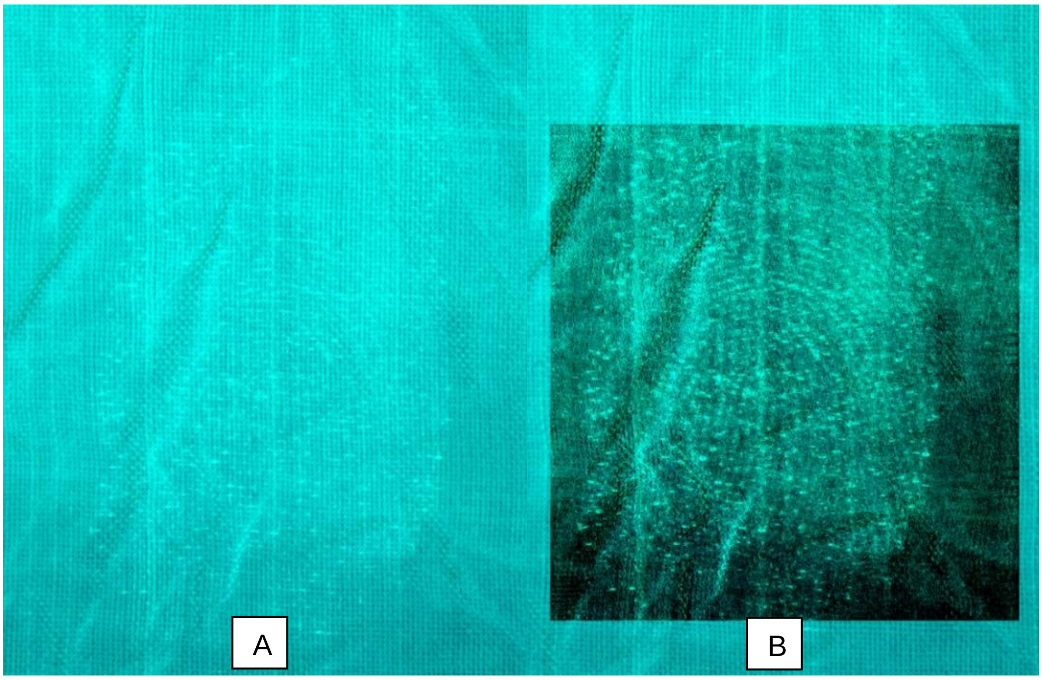


Figure 11.4: CAF-visualised silk donor A sample; (A) displaying poor ridge detail and (B) same sample after FFT with ridge detail enhanced (Deacon 2012a).

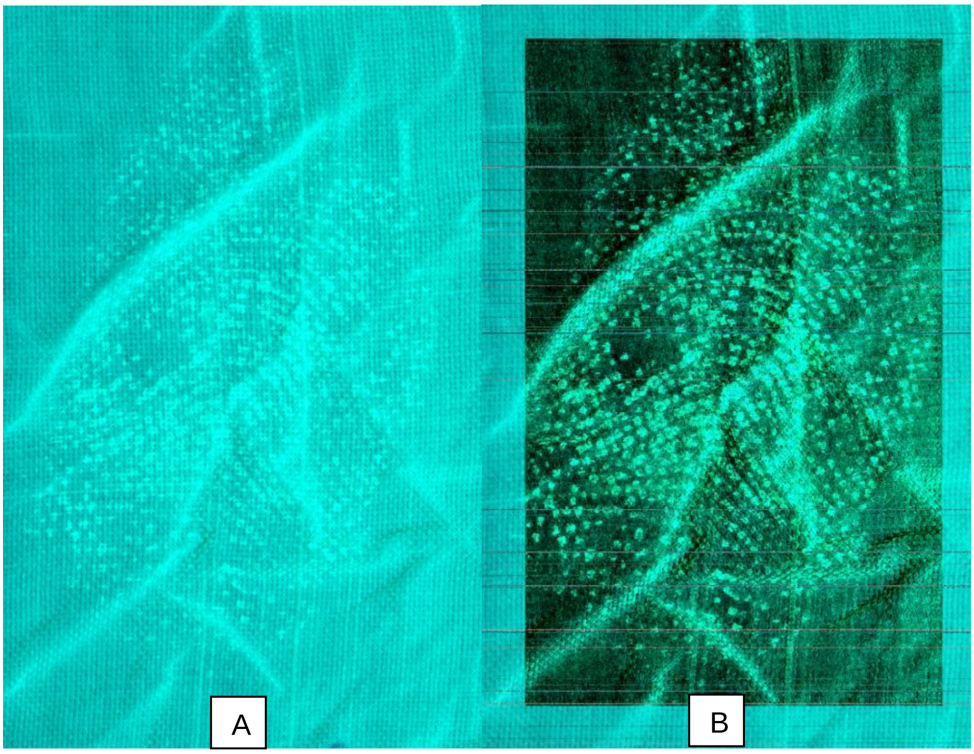


Figure 11.5: CAF-visualised silk donor C sample; (A) displaying poor ridge detail and (B) same sample after FFT with ridge detail enhanced (Deacon 2012b).

CAF did not visualise any marks on cotton and, to begin with, VMD would not even coat the fabric, however once the metals adhered only empty marks were visualised. Donor A and donor B were positive for all the planted marks, though donor C was negative for all the planted marks. This was surprising as donor C was generally a good donor, so it would have been expected for them to, at the very least, leave empty marks. Though as the cotton used had a rougher surface structure than the silk used in this study these results are not unexpected from what has been determined previously.

Polycotton was also negative for all the CAF grids, however in the VMD grids – donor A was positive, if empty, for four of the squares (3, 10, 11 and 18), while one (square 2) was quite faint, therefore though could be considered positive it would not be accepted as a mark operationally. Donor B was positive for three of the squares (4, 7 and 16); though two squares (9 and 12) were negative. This is not unexpected as this donor is considered a poor donor and polycotton is a fabric that has been shown to be less successful at visualising marks and ridge detail. Finally, donor C was positive for all the VMD planted marks, though no ridge detail was seen. This person is considered a good donor, so there was a high expectation that the marks would be seen, thus the absence of some ridge detail was disappointing.

Therefore, overall, the donors and fabrics seem to follow the same pattern as the other studies. Donor A was a medium donor, while donor B was poor and donor C was good. Considering the fabrics, the CAF grids followed the now expected pattern of little or no detail for cotton and polycotton, both were negative for all planted marks, while the silk was positive though no detail was observed. The results from the VMD grids followed a slightly different pattern, with cotton (only 10 out of 15 plants), followed by silk (11 out of 15 positive) and polycotton (12 out of 15) being positive. If the silk and polycotton followed previous results, they would have been expected to be the other way round with silk having more positive marks and even ridge detail. This unexpected result is most likely down to the silk grids and planted marks being too fresh, thus the VMD not being able to visualise the marks or any detail (Deacon, P. 2012. pers. comm., 1 November).

The second part of the blind trial involved the use of three swatches of each fabric and the donors planted marks on only two of them [Table 11.7]. These were then sent to SPAFS for processing and assessment of the resulting marks. Again, the VMD processed samples visualised more positive grab results (16 out of 18) than the CAF (2 out of 18).

Table 11.7: Results for grabs visualised with VMD or CAF on silk, cotton and polycotton for donor A, B and C (X indicates a fingermark or mark, while O indicates where a mark had been planted, but was not visualised).

VMD	Silk			Rayon			Polycotton		
Position	A	B	C	A	B	C	A	B	C
1	X		X	X	X	X			X
2		O		X		X	X	X	
3	X	O	X		X		X	X	X
CAF	Silk			Rayon			Polycotton		
Position	A	B	C	A	B	C	A	B	C
1			O	O	O	O	O	O	O
2	X	O			O	O	O		O
3	X	O	O	O				O	

Of the CAF samples, the cotton and polycotton were all negative samples with none of the planted grabs being visualised. Though A was not the best donor in the grab trial, all the planted grabs on silk were positive and contained a recognisable pattern and some ridge detail, though not enough for an identification.

The VMD samples only had one negative set (donor B; rayon), and while all other grabs were visualised, donor A, silk and donor C, polycotton contained only empty marks. Donor A, rayon was positive for the correct samples (no false positives were detected); though there were only empty marks and the grabs were not full hands. Polycotton did have full hand grabs for the correct samples, but did not contain ridge detail in any of the fingertips or any palmar flexion creases. With the silk samples the positive samples, had no ridge detail, but did contain palmar flexion crease, which could help with identification. Donor B was negative for rayon and even though the correct samples were identified for polycotton and silk, there was no ridge detail in any of the grabs. Donor C had the most visible detail of all the donors. Rayon and silk were both positive for the correct samples, but neither fabric contained ridge detail. However, the most detail was seen on polycotton samples, with palmar flexion creases in one instance identifiable marks in the other.

In conclusion, even though both the grids and grabs blind trials, do not completely follow the results obtained previously (for example, silk did not produce as many positive marks) these experiments did show that other individuals can process fabrics using VMD and CAF to visualise marks, both empty and with identifiable ridge detail.

12. NOVEL APPROACHES

12.1 Sputter coater and Adroit FC-3000

Operationally, VMD uses gold + zinc, though occasionally silver metals on case work, however other metals have also been examined. Philipson and Bleay (2007) investigated several different metals, such as copper, silver, gold, tin and indium, on different plastic substrates. They determined that it was copper and silver that visualised identifiable marks while the others had more limited success, thus copper as well as silver were investigated further and compared to the traditional gold + zinc. These comparative results were mixed, with copper not producing better results than silver except on PVC cling film, therefore was excluded from the rest of the study; gold + zinc also did not always give the best results and on several occasions only visualised empty marks. The empty marks may have been as a result of high levels of fatty fingerprint residues migrating into the valley portions of the marks thus "blurring the lines" of the ridges due to high gold diffusion. They also found that with silver, further detail could be observed after 24 h, and suggested that productions be re-examined after a passage of time. The use of silver VMD has also been examined during this current study and the results can be seen in section 7.13 as well as Knighting et al. (2013) [Appendix 15.1.2].

Not everyone used commercial VMD machines. Kent and Stoilović (1995) carried out sputter coating, using four different metal targets – gold, platinum, zinc and copper, on polythene bags (fresh and one year old). They found that copper and zinc showed good results on the fresh and year old samples, but only poor results from the third depletion onwards. However, the gold and platinum were found to be the best and they went on to compare the platinum sputter coated samples to those visualised with CAF and rhodamine 6G staining. Here the sputter coated samples were found to be higher in sensitivity and produced superior results than the CAF samples. Sputter deposition with gold was also utilised by Turner et al. (2010) as an alternative to VMD or CAF and successfully visualised 12 to 16 identifiable minutiae on glass slides as well as on polyvinyl chloride acetate and polyethene substrates that had been immersed in water for seven days. Overall, they deemed that the sputter coater marks were clearer than those produced by either VMD or CAF. They also felt that the lower running and maintenance costs of the sputter coater made this a more affordable alternative, and so the "technique of choice for the development of latent marks on non-porous surfaces" (Turner et al. 2010, p. 19). Though this was not tested on fabrics, third level detail was observed on non-porous glass microscope slides and plastics. Work was also carried out with copper phthalocyanine in a modified vacuum desiccator producing "excellent ridge detail clarity on light coloured surfaces" (Williams et al. 2011, p. 28) on paper (a porous substrate and comparable to fabrics). Yu et al. (2011) examined the use of zinc oxide in a thermal evaporator, on plastic substrates with comparable results to gold+zinc VMD. The zinc oxide however, did not need gold to aid in attachment to the fingerprint residues and was found to visualise marks aged for 45 days more effectively than VMD. Aluminium has also been investigated as an alternative to the traditional to gold + zinc. Aluminium and gold +zinc were compared by Gunaratne, Knaggs and Stansbury (2007) on different plastics using split marks over a timeline of less than 48 hours to over 90 days. They found that aluminium was more successful on the younger marks, producing more detail and of better quality, whereas gold + zinc was superior on the older marks. Therefore they suggested that aluminium is a good metal choice, though both methods should be considered for older marks. Overall, the techniques do seem to have achieved the visualisation of fingermarks therefore the current study attempted to emulate this by utilising a sputter coater (SEM coating unit PS3).

In order to imitate a miniature VMD chamber, the metals nickel, copper and aluminium were heated under vacuum in a sputter coater. These metals were chosen as they are reasonably easy to purchase and relatively inexpensive, thus accessible to all researchers and police departments. Lead, platinum and magnesium were also suggested, but although lead and platinum gave marks with "good contrast" in the Atomic Weapons Research Establishment (AWRE) studies (Coles and Stroud 1973), lead was excluded in the current research due to health and safety reasons and platinum was too expensive. In the AWRE studies magnesium gave marks with good detail, however needed "a high incident flux" which was not possible with the equipment used in this study (Collins, Coles and Stroud 1973). As with previous studies described in this thesis the timeline chosen was in relation to when violent crimes are reported, generally within the first few days, (Kelly, Lovett and Child 2005) and due to the first collection being taken on a Friday it was processed on the Monday, thus was day 3.

12.1.1 Three Days Old

With nickel, no deposits were observed on nylon, white satin, cotton or black satin, though the (apparent) lack of metal deposition on black satin may have been due to the darkness of the fabric rather than no nickel being deposited. Polycotton had minimal deposition after the full 300 seconds, but no fingermarks were observed. With polyester and nylon-Lycra there was a visual deposition of nickel after 30 seconds and after 60 seconds with linen, but no marks where the marks were planted were obtained.

The copper target also resulted in little deposition occurring or any marks being observed. Nylon-Lycra had a definite deposit but no mark or detail was seen, while cotton had a better coating than with nickel, but there was still no indication of a mark. An extremely faint deposit was observed after 30 seconds on polyester, however no mark or detail was observed even after the full exposure time (300 seconds). Linen, polycotton and white satin had extremely faint deposits after 60 seconds, but again no marks or detail was observed after 300 seconds. The nylon had more copper deposited during successive coatings, however there was no indication of where the mark was planted and, black satin had no deposit at all, though as previously stated this may be due to darkness of fabric.

The aluminium target was the poorest of all three of the targets used in the study and it took over 60 seconds for any deposits to be observed on nylon, 90 seconds for cotton, 120 seconds for white satin, 180 seconds for linen and nylon-Lycra and 240 seconds for polycotton. No marks or detail of any kind were observed on any of these fabrics with hardly any deposits on polyester and nothing observed with black satin.

12.1.2 One day old

As the results did not produce any marks or detail of any kind the delay between planting the marks and processing was reduced to one day, though this did not improve the detail visualised. With nickel, there was no deposit at all with black satin; only a faint deposit but no marks or detail for nylon and white satin after 30 seconds, polyester and cotton after 60 seconds; nylon-Lycra after 90 seconds; linen after 120 seconds and polycotton after 150 seconds. Copper was similar in the lack of deposition and marks; and polycotton only had minimal copper deposits after 60 seconds, but no marks or detail observed even after the full 300 seconds. With nylon, polyester and white satin there was minimal deposits of aluminium from 60 seconds onwards but no marks observed, while with cotton and linen it took 90 seconds for any aluminium to be observed. Nylon-Lycra was a bit more unusual in that there was a faint deposit on some outer areas of the swatch after 30 seconds with more metal being deposited after another 30 seconds, with a possible mark being observed after 120 seconds and irregular deposits at 150 seconds, but no ridge detail was observed at any time. On the black satin at 300 seconds it could be seen where the mark had been planted, but this was not enhanced by further deposits. In fact, as more metal was deposited it made the mark harder to see, and there was the impression that the metal was coating the whole substrate surface including the mark. Finally, with the aluminium target there were no marks or detail of any kind and it took 60 seconds for even a minimal coating on polycotton, nylon and white satin; 90 seconds for cotton and linen; 150 seconds for any coating to be observed on polyester and a full 240 seconds before any deposits of aluminium was observed.

12.1.3 Zero days old

As none of the targets visualised any detail or even any areas that might have been where the mark had been planted on the swatches it was decided to plant the marks and try visualising them on the same day. Thus, day 0 followed the same processes – marks were planted on the swatches and then after an hour were processed with the appropriate metal. Nickel, again showed no detail and no planted marks were visualised. There was no deposit of metal at all on nylon-Lycra; while after 30 seconds there were only faint deposits for nylon and cotton; the same for white satin and polyester after 60 seconds; 120 seconds for cotton and 150 seconds for linen. For black satin there was a possible mark after 180 seconds and by 300 seconds there was a faint difference between background and planted mark, though this may have been due to the colour of the fabric allowing the mark to be visible from the planting stage. Copper left no deposit or made any marks visible for the whole 300 seconds on polycotton. While nylon, cotton and polyester only gave extremely faint deposit after 30 seconds, and though these deposits became darker after 60 seconds no marks or marks became visible. Copper deposits only appeared on white satin and linen from 60 seconds onwards, but no marks were visualised. With nylon-Lycra faint deposits were viewed from 90 seconds, which although they became stronger did not visualise any marks. With the black satin, an oval shape was observed where the mark had been planted, but no detail was observed. Again this mark could be seen at the start, as with other black satin samples, but in this case the mark did become more obvious from 150 seconds, though once more no ridged detail was observed. When aluminium was tried, the cotton only had a faint coating after 30 seconds, but no marks or detail was observed after the full 300 seconds. Nylon, gave extremely faint deposits after 90 seconds, but no marks or detail observed after 300 seconds; and both white satin and polyester displayed an extremely faint deposit after 150 seconds with minimal deposit overall and no marks. While black satin displayed a partial mark at 150 seconds, this was not the full outline of a fingermark and may have been due to contamination rather than fingerprint residues. Minimal metal deposits were seen on linen at 180 seconds, polycotton at 270 seconds and nylon-Lycra only showing some deposition at the very end (300 seconds).

Therefore overall, when comparing all three metal targets even though there was little deposition of the metals and no real marks, they can still be rated in their ability to coat the fabric from the best to worst - copper, nickel and aluminium.

In conclusion, the sputter coater used in this study did not provide any ridge detail and only limited success in visualising the area a mark had been planted. There were possible outlines on black satin for copper and nickel on day 0 and with copper on day 1 with a slight mark also on aluminium for day 0. However, there may be more success in using these metal types in a full sized VMD machine, as in the case of the work carried out with silver VMD by the Home Office in 2005 and by Philipson and Bleay in 2007. For example, the Adroit FC-300 latent mark development system has been developed by The Linde Group Canada and though this is marketed as a system to develop fingermarks with ninhydrin, cyanoacrylate and sublimation dyes (Swofford et al. 2012). The Adroit FC-300 has also been used to vacuum coat with aluminium (Knaggs, C. 2010. pers. comm., 2 August) with considerable success with full ridge detail visualised [Figure 12.1]. Therefore this technique could be used in a similar manner as a VMD machine, however, the Linde website and literature state there are several advantages of this piece of equipment over the traditional VMD. The Adroit FC-300 has a non-stick coating on the chamber walls, therefore is easier to keep clean and to clean; that the table on which the work holders stand rotates 360 ° therefore allows the person processing the samples to view ever side and surface of the sample as well as the viewing port can be lit with multiple light sources, including lasers and alternative light sources (The Linde Group 2013). Therefore with these advantages and the success of the use of aluminium is a good reason that this piece of equipment should be investigated further as to its usefulness in visualising fingermarks on fabrics.

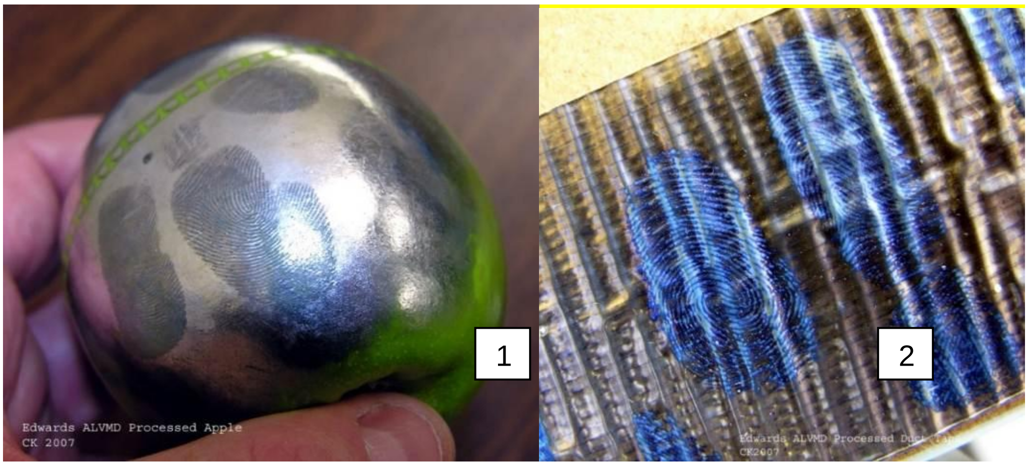


Figure 12.1: Fingermarks developed on an apple (1) and duct tape (2) using aluminium metal in the Adroit FC-300 (Knaggs 2007).

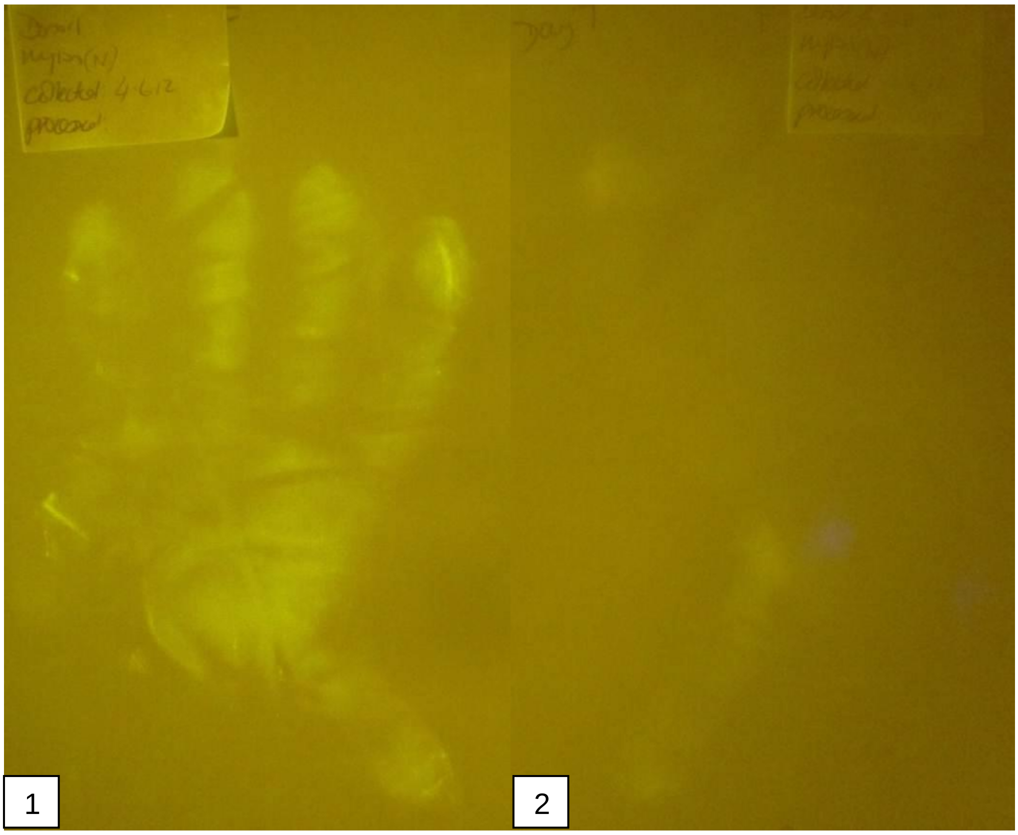


Figure 12.2: Grabs on nylon visualised with dye sublimation in the Adroit FC-300. Donor one (1) has a full hand and palmar flexion creases, but no ridge detail in the fingers while donor two (2) only contains a faint finger and thumb mark (Knaggs 2012a).

As part of the current work, some fabric swatches, containing planted latent marks, were processed using the Adroit FC-300, though with dye sublimation (Linde LR1 dye) rather than metal deposits. All the samples were aged for two weeks, processed with the Linde LR1 dye then photographed with a Nikon digital camera fitted with an orange filter and using a 440 nm light source. Figure 12.2 shows an emailed photograph of a swatch that had marks planted in UK and then processed in Canada. Although the results were not as successful as the aluminium images shown in Figure 12.1 or some of the VMD processed swatches, they did visualise hand grabs and it is believed that once the correct cycle has been determined then samples will be obtained with more defined detail. It was found that nylon [Figure 12.2], silk [Figure 12.3] and polycotton appeared to most readily allow the areas that had been grabbed to be visualised, while Lycra, cotton and linen [Figure 12.3] required more work to determine the "optimum technique" (Knaggs, C. 2012. pers. comm., 12 June).

Figure 12.3: Grabs on silk and linen visualised with dye sublimation in the Adroit FC-300. The silk sample is a full hand with palmar flexion creases and empty marks, while the linen only contains faint finger and thumb marks with little palm visible (Knaggs 2012b).

From the emailed photographs it was determined that there was no visible ridge detail, however after refinement of the technique and possibly use of fast Fourier transform (FFT), ridge detail may be observed with the sublimation dye. Also, further work could involve the use of metal rather than dyes and this may improve the detail even further. Nevertheless, this brief examination using the Adroit FC-300 supports the VMD and CAF work reported herein where the tighter and smoother the weave the more detail that will be visualised.

While ridge detail was not produced the operator stated that the "dye sublimation process was found not to interfere with DNA so if this can be confirmed using fabrics it may be useful for presumptive testing and locating DNA on clothing." (Knaggs, C. 2012. pers. comm., 23 May). Thus, as seen in the VMD and CAF work, if ridge detail is not visualised there is still the possibility of recovering DNA which can help lead to an identification.

Therefore, though the sputter coater work described here was not effective there was some success reported in the past with trials by Kent and Stoilović (1995) and Turner et al. (2010). However, as seen by the work carried out by Knaggs it is possible to visualise excellent ridge detail on non-porous substrates.

12.2 Nanoparticles

12.2.1 Aim

To investigate the production of fluorescent nanoparticles and examine their possible use for visualising latent fingermarks.

12.2.2 Introduction

Much work has been carried out over the years on nanoparticles in relation to their use in visualising fingermarks. This has included the detection of drugs (Hazarika et al. 2008, 2010; Leggett et al. 2007) and amino acids (Spindler et al. 2011) in fingermark ridges and the production of fingerprint powders containing nano-scale particles (Theaker, Hudson and Rowell 2008). There have also been advances in the use of precious metals, such as gold (Becue, Champod and Margot 2007; Choi et al. 2008b; Schnetz et al. 2008; Gao et al. 2009; Fairley et al. 2012) and silver (Sametband et al. 2007) to visualise marks. The above research comments on how these particles can adhere to the ridges making them visible via fluorescence, either from the nanoparticles themselves (Hazarika et al. 2008, 2010) or from moieties attached to the nanoparticles, such as gold (Fairley et al. 2012) or fluorescent dyes (Theaker, Hudson and Rowell 2008) study.

Some studies (Hazarika, Jickells and Russell 2008, 2010; Leggett et al. 2007) utilised antibodies to the drug metabolites of marijuana, methadone, cocaine and nicotine. As these metabolite compounds are excreted from the body in sweat and, since this is one of the main components of fingerprint residues, the fluorescentlytagged antibodies attaching to the metabolites causes the whole or parts of the fingermarks containing the metabolites to fluoresce, thus become visible and identifications made. All of these studies stated that "lifestyle intelligence" (Leggett et al. 2007, p. 4100) can be gleaned from the fingermark and if the individual has ingested drugs, their metabolites will be excreted onto the skin and identified. It was also cautioned that care must be taken in the identification of some metabolites. For example the detection of morphine could be an innocent result of the individual being administered with codeine rather than morphine (Hazarika et al. 2010).

Amino acid sensitive fingerprint reagents, such as ninhydrin and 1,8-diaza-9-fluorenone (DFO), have been used historically but more recently in the form of Genipin and Lawsone (Jelly et al. 2009), however Spindler et al. (2011) utilised the antibodies of the amino acids conjugated with gold nanoparticles to visualise the fingermarks. In this case the conjugated gold/amino acid marks outperformed the unconjugated anti-L-amino acid antibody marks with more and better detail being observed.

Metals, especially gold, have been the most widely used in the production of nanoparticles either in the form of colloidal gold or multimetal deposition (MMD). This is illustrated in the use of gold nanoparticles to attach to fingermarks, and then act as sites of attachment for silver particles producing dark ridge detail (Becue, Champod and Margot 2007). Though this is an improvement on the traditional method there are still several steps and this limits where this process can be performed. In a later paper the use of zinc oxide rather than silver as the material adhering to the gold nanoparticles was reported (Becue et al. 2008). The zinc oxide (ZnO) could be seen clearly under white light and produced a white coloured fingermark as well as under UV (300-400 nm) to produce a green colouration to the mark, which is extremely useful if the substrate is dark. Both processes were successful in visualising detail on a variety of substrates and ages of marks and improved on the more traditional MMD formulations. A further reduction in steps was reported by Gao et al. (2009) leading to clearer marks due to a lack of background interference, more defined ridge detail and a red colouration to the marks themselves. The nanoparticles could also work in a wider pH range, 2.5 - 5.0 compared to the 2.5 - 2.8 of the traditional MMD method, which makes it easier and more practical for everyday laboratory use. Stauffer et al. (2007) also found that by replacing the silver enhancement of gold colloids by a gold enhancement procedure, there was a reduction of the number of baths and reagents used, therefore a reduction in cost, labour and an improvement in the shelf life of the solution.

Sametband et al. (2007) investigated the effect of introducing the gold nanoparticles into the silver physical developer process. They found that though the traditional method of silver physical developer did produce marks, the quality was enhanced by the presence of gold nanoparticles dissolved in petroleum ether and stabilised by n-alkanethiols. They also determined that the length of the n-alkanethiol chains was linked to the quality of the marks developed in that the longer chains produced clearer marks.

With all the different studies into nanoparticles two papers collated and compared the different methods of nanoparticle fingermark visualisation have been published (Choi et al. 2008b; Fairley et al. in 2011). The former review discussed metal particles, metal oxide particles, metal sulphide and other metal-containing particles. With the metal particles, such as MMD and SMD in solution, it is the positively charged amino acids and proteins of the fingermark that attract the negatively charged gold nanoparticles. These then form sites of nucleation for the silver in the physical developer, leading to increased enhancement of fingermarks. Generally, this was more effective than silver developer on its own and better or equal to VMD and CAF on plastics, but less sensitive than DFO or CAF on dry substrates. The authors conclude that improvements in single metal deposition (SMD) has produced results on the same level as MMD and nanoparticles in fingerprint powders has led to cleaner, sharper development of marks, with less staining in the background. The Fairley et al. (2012) paper compared the different MMD techniques and their use on substrates, such as cling film; leather plasticized vinyl and masking tape that do not generally allow good development of fingermarks. The overall conclusion was that the most successful method was colloidal gold followed by physical developer with reduced pH (Schnetz and Margot 2001). However, it was found that this method, though better on cling film and plasticized vinyl, was ineffective on masking tape and leather.

The majority of the nanoparticle methods already discussed have involved gold. However, Theaker, Hudson and Rowell (2008) described the use of fluorescent dyes that were embedded into the nanoparticles, which produced a fingerprinting powder that could visualise marks of various ages and due to being a traditional dark powder with the fluorescent particles embedded, the marks could be readily viewed in both white and UV light. The Choi et al. (2007, 2008a) studies also reported titanium dioxide and zinc oxide powders, which were used on glass, polyethylene and aluminium foil. These were viewed under UV light and the fluorescence produced allowed the latent fingermarks to be visualised, and in the case of the titanium dioxide powder good visualisation of ridge detail to the third level on the glass slides was observed.

These powder processes seem relatively simple, however many of the techniques described above use complicated or multi-step processes; require scrupulously clean glassware; and doubly distilled water in order to prevent any nucleation or development of colloidal gold on areas other than the fingermark ridges (Schnetz and Margot 2001). Consequently, it was decided to look into the possibility of producing a solution that would be easily prepared and then applied to the latent marks in simple steps causing the marks to fluoresce, thus allowing them to become visible.

Carbon nanoparticles that fluoresce would seem to be a possible area for advancement in visualisation of latent marks. Sun et al. (2006) reported that quantum-sized dots produced a stable photoluminescence, while the Ray et al. (2009) study produced multiple sized nanoparticles that emitted differently coloured light depending on the wavelength at which the particles were excited, from blue-green with UV to yellow with blue excitation. These nanoparticles had been produced from the oxidation of carbon soot, as were the particles produced by Tian et al. (2009), which also produced photoluminescence. It was, however, the papers by Li et al. (2011a, 2011b) that reported fluorescing carbon nanoparticles via ultrasonic treatment where were of most interest. Here, the particles were produced from an active carbon/hydrogen peroxide solution or a glucose/sodium hydroxide solution treated ultrasonically. The resulting nanoparticles emitted strongly in the near infra-red and visible spectrum, therefore work was embarked upon to determine whether these carbon particles could be used to adhere to, and therefore visualise, latent marks.

12.2.3 Nanoparticle production

Glucose and hydrochloric acid (HCl) as well as glucose and sodium hydroxide (NaOH) were separately sonicated for 6 h at 20 kHz. Initially, the solutions were clear and colourless and remained this way until the water was evaporated and the solution turned progressively darker until a thick dark brown/black slurry was produced which was diluted with distilled water for further investigation. In another set of experiments, coffee and activated carbon cloth suspensions were also sonicated (1 h and 6 h respectively at 20 kHz) to afford, after filtration, a clear colourless solution.

Each solution was then placed separately into the spectrofluorophotometer and observed under the wavelengths of 300 nm to 900 nm. The glucose/HCl solution pre and post filtering, pre and post evaporation, sonicated and diluted (1:10 in distilled water) displayed nearly the same colours at each wavelength, while the control glucose solution was slightly different from 600 – 900 nm. The same was observed with the glucose/NaOH solutions, the coffee solutions and the carbon solution, with only slight variances in tone rather than colour. Thus, it was determined that the colour being emitted was from the spectrofluorophotometer and not caused by any fluorescence from the solutions themselves. As this was unsuccessful the solutions were observed using a fluorescent microscope.

The solutions were tested neat and diluted with distilled water (1:1 - 1:10) and placed on glass slides and viewed under the different cubes of the microscope. The different cubes used were: 1 H, UV excitation range and excitation filter (340 – 380 nm); 2 H, UV/violet excitation range and excitation filter (355 – 425 nm); 3 H, blue excitation range and excitation filter (450 – 490 nm); 4 H, green excitation range and excitation filter (515 – 560 nm).

The colours were nearly the same for each dilution and each solution – glucose/HCl, glucose/NaOH and coffee. For 1 H the backgrounds were all blue, ranging from dull to bright with some solutions containing some clusters of particles; for 2 H the backgrounds were yellow or yellow/green with green clusters; with 3 H the backgrounds were green to bright lime green with green clusters; and finally the 4 H had a dull red to bright red background with bright red clusters. The components of the solutions (ethanol, HCl, glucose and water) and the slides were also examined and they too exhibited the same colours, but were all dull with no fluorescence – 1 H were all blue, 2 H were all yellow or yellow/orange, 3 H were all green and 4 H were all red.

All the previous samples had been smeared onto the glass slides, so in an attempt to determine whether it was the application that led to a lack of particles and limited fluorescence an alternative method was tried. The solutions were applied by pouring directly over the slides, dipping the slide into the solutions for approximately 2, 10 or 30 seconds or painting the solution onto the slide with a soft natural hair paintbrush and, this time, the size of the smallest particle was also measured. This was carried out on plain clean slides as well as slides that had a mark planted one hour prior to the solutions being applied. Again the colours observed on the slides and the fluorescence of any particles was extremely similar for all solutions and methods of application. The solutions were observed at x400 and x50 magnification – 1 H the background colour was pale blue with blue or bright blue; 2 H had a yellow background with bright green or white with green outlines to the particles; 3 H had a bright yellow or yellow/green background with green or dark lime green particles; and 4 H had red particles on red backgrounds, while the particles ranged in size from 0.69 – 624.72 μm, thus were not nanoparticle sized.

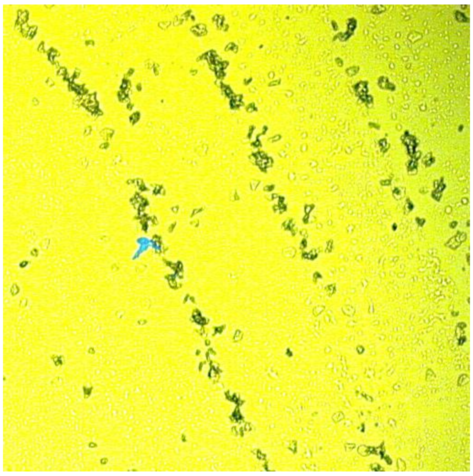


Figure 12.4: Planted mark coated with putative nanoparticles from coffee sonicated for 1 h, photographed at a magnification of x50. Ridge detail in the form of skin cells and particles is visible on the slide.

The particles that were observed did fluoresce, but did not adhere to the marks that had been planted and in some cases the mark actually appeared to repel the solutions, therefore 10 % AEROSOL OT detergent solution was added to help overcome this issue. At x50 magnification, it was possible to see some of the particles attached to the ridges [Figure 12.4], but there was not enough of the mark visible to be able to identify an individual. Therefore, it was necessary to view the samples in such a way as to allow the whole of the mark to be seen, so they were viewed under the Crime lites and Quaser.

With all the Crime lite samples, which were on glass and paper (both recycled and bleached) the majority were negative. Some of the paper fibres fluoresced, while on others the outline of where the mark had been planted or the edge of the solution could be seen, but there was no detail. Use of the Quaser followed the same pattern with every single possible combination of settings tried being either negative, with only a few samples displaying the solution front, or some of the fibres in the paper samples fluorescing.

Overall, the production of fluorescing nanoparticles was not achieved at this time even after following the method of Li et al. (2011a). There was some fluorescence at the solution front edge and some particles, though probably not nano-sized. There was an improvement from the original starting solution by the addition of a detergent, which enabled the solutions to adhere to the planted marks, but any particles that could be viewed under the microscope were not visible under the Crime lites or Quaser. Thus, more work is necessary to further refine the methodology to produce nanoparticles that can adhere to marks, fluoresce and be seen under the Crime lites or Quaser.

13. CONCLUSIONS

13.1 Visualisation of latent marks

When considering all the data, vacuum metal deposition (VMD) is the most successful technique for visualising latent fingermarks, palmar flexion creases and grab marks on fabrics throughout the study's 10 day timeline (days 1 – 28) as well as on samples that were over 4 years in age (Fraser et al. in press). In the majority of the study, the traditional method of gold + zinc was used and this was reasonably successful in visualising ridge detail and grab marks on the lighter coloured fabrics, however silver VMD was deemed more successful on the darker fabrics (Knighting et al. 2013). Cyanoacrylate fuming (CAF) did visualise marks, however the ridge detail observed was in many cases not at the same level as VMD. With CAF there was also the issue of the background fluorescence caused by the basic yellow 40 (BY40) dye possibly obscuring detail on the samples. If this issue could be solved CAF may have significant advantages over VMD, such as reduced costs and availability of the equipment, making it the method of choice. Other techniques, such as 1,8-diaza-9-fleorenone (DFO), small particle reagent (SPR), ninhydrin and fluorescent powder had limited success probably due to these materials reacting as much with the fabrics as the fingerprint residues thus the whole surface becoming coloured and the fingermarks not visible. Also, attempts at utilising alternative metals in conjunction with the sputter coater, were largely unsuccessful though the use of the Adroit FC-3000 may be promising. Similarly, attempts at producing nanoparticles were not successful and therefore their effectiveness in visualising fingermarks could not be evaluated. In conclusion, VMD appears to be the best technique in that it visualises more detail on more fabric types, with most donors over the full timeline used.

13.2 Sequential treatment of samples

It was found that sequential treatments with VMD then CAF on the smoother, manmade fabric showed more improvement on detail whereas the natural fabric, linen showed no improvement, which indicates the fabric surface is probably influencing the detail observed. The addition of humidity from the CAF may also be affecting the attachment of the metals to the fabrics and so decreased the detail was observed. With CAF then VMD there was no extra detail observed by this order of treatment of fabric with the exception of nylon-Lycra, which did increase in detail. Overall, there is little benefit to sequential treatment especially if CAF is used first.

The use of CAF after VMD does seem to increase the detail due to the use of BY40 after the CAF enhancing the contrast between the metal deposits and the, now, yellow background fabric colour. In some cases such treatment was detrimental and even reduced the level of detail originally observed. There may also be the possibility that the BY40 is obscuring detail, visualised by the CAF, due to background fluorescence, therefore considerably more detail may be present on the fabric but cannot be observed.

13.3 Fabric type

Generally, fabrics such as nylon, satin and silk, which are porous, and have smoother, tighter weaves, displayed higher levels of detail. Porous, rougher and more open weave fabrics, such as cotton, polyester and polycotton, exhibited less detail. Most fabrics showed some level of detail indicating that it had been touched, in some cases only a possibility of a fingertip mark, and this could help a technician to target areas to tape for DNA. The fabric type and its effect on the level of detail visualised is discussed in more detail in each of the thesis' published papers – Fraser et al. 2011, Fraser et al. in press and Knighting et al. 2013. These papers can also be found in appendix 16.2.

It was also observed that the more hydrophobic a fabric, the less the residues are absorbed into the fabric and therefore are more available to the visualisation technique and hence, an increase in detail visualised. Whereas hydrophilic fabrics allow the residues to absorb into the fabric thus are not available, therefore a reduction in marks visualised. Fabrics may also have coatings that can affect how well the fingerprint residues adhere to them and these can be removed through washing and wearing. The wear and tear of a fabric surface could also lead to a reduction in detail, due to conversion from a smooth to a rougher surface structure.

13.4 Donors

Donors seem to be one of the biggest variables and in this study they ranged from good to poor. Generally, a good donor, who produces a large amount of fingerprint residues, will give better ridge detail than a donor with drier hands or reduced levels of residues. This too is discussed in the published papers, however it must also be noted that a donor who is considered good may not always leave excellent detail due to changes in health, diet and environment. There were times where good donor samples did not show detail and there poor donor samples that unexpectedly showed good detail. Therefore, this illustrates the variable nature of fingerprint deposits and fingerprint residue production.

13.5 Palmar flexion creases

Not all donors left ridge detail in the finger tips, but many left palmar flexion creases and though this detail is not always considered during police investigations but is becoming more important as potential evidence. Approximately 30 % of all latent marks found at crime scenes are in the form of palm marks (Sutton et al. 2013), therefore these recovered marks and the fact palm marks are now recorded during the booking process of suspects, shows they are a useful tool in the connecting of individuals to crimes. In addition, if the nature of the crimes that involve the processing of clothing, such as sexual and physical assaults is considered, it would be expected to involve the suspect grabbing and pushing the complainant. Therefore, there would be a high possibility that palms would be placed on the items of clothing and then may by visualised if processed and so aid in identity.

13.6 Age of mark

Generally, fresher marks developed higher levels of detail, although, with the correct conditions such as a good donor and a smooth tight weave fabric older marks can also be visualised. However, even samples, which were up to 4.2 years old (discussed in the cold case section 10.3), gave some palmar flexion creases indicating the areas of the item that had been touched therefore could be used to show a sequence of events and as a place to target for DNA.

13.7 DNA recovery

The use of DNA in producing an identification, was illustrated with samples that were visualised with VMD, where it was determined that it was possible to collect partial and full DNA profiles. Therefore this work carried out with VMD samples along with literature stating that the cyanoacrylate (CA) polymer encapsulates the DNA making it available for collection means neither process should prevent the collection of DNA thus identifying the individual that touched or grabbed the fabric. Nevertheless, where no ridge detail was visualised with either process, the empty marks could still be targeted for taping and DNA collection that could lead to an identification.

This collaborative work has been submitted to Forensic Science International Genetics for publication and is awaiting review.

13.8 Recording of ridge detail

There were several problems with the recording of detail on the samples and either infrared (IR) or fast Fourier transform (FFT) imaging could be the solution to the problem of recording the level of ridge detail as viewed by the operator on the processed item. The human eye appears to be able to discriminate between the fabric weave and the ridge detail on the fabric, whereas a digital camera appears to record the marks, ridge detail and the fabric weave. Potentially, the marks could be recorded using an IR camera or, alternatively, a regular digital camera could be used followed by processing with FFT. Both of these techniques were used in a limited manner during this study (see section 3.24) and some extra detail was found.

13.9 Effect of moisture on detail observed

There are several factors, such as the levels of water applied to the fabrics, that led to changes in the level of detail observed. An increase in water generally led to a decrease in detail and this was more obvious with CAF compared to VMD which reinforces the literature view, that states that VMD can be used on substrates that have been exposed to adverse aqueous conditions and that CAF does not easily visualise marks on items that have been wetted.

13.10 Original contribution

Very little work has been carried out in the past in relation to fingermark recovery from fabrics using VMD and much of it is anecdotal and, if it was published, it took the form of technical reports and notes. Work reported in this thesis has detailed the methodology and operational parameters necessary to optimise the technique of VMD and has utilised a massive study involving nine different fabrics: cotton, polycotton, polyester, nylon, nylon-Lycra, satin, silk, rayon and linen along with fifteen donors ranging in age, sex and ability to leave fingermarks. The samples were collected and processed with the appropriate technique over various time periods, generally, 1, 2, 3, 4, 5, 6, 7, 14, 21 and 28 days.

For the first time, a direct comparison of the use of VMD versus CAF has been carried out and that it was found that both VMD and CAF did visualise marks and ridge detail from latent fingermarks. Statistical analysis showed that VMD the most suitable technique for development of fingermarks on fabric, with gold + zinc VMD best for light coloured fabrics and silver VMD for dark. CAF also visualised several identifiable marks, even with the problems of background fluorescence from the basic yellow 40

(BY40) dye used to visualise the cyanoacrylate (CA) polymer. It was found that the smoother fabrics with a tighter weave, such as nylon and silk allowed the visualisation of more detail than rougher and/or looser weave fabrics such as cotton and linen. The latter tended only to show empty marks or marks, which gave indications of where the fabric had been touched. However, fabrics that did show marks, even if not suitable for identification, could still give information as to the sequence of events that may have occurred during an assault as well as identifying an area to tape for DNA. It was determined that it was possible to collect DNA from VMD visualised marks which led to partial and full profiles of those who touched and grabbed the test swatches or items of clothing tested.

This study expanded on, yet, validated the previous work on VMD, but also describes the new and novel process of combining multiple fingerprinting techniques to determine their effectiveness. With sequential treatment, the optimum sequence was VMD followed by CAF, due to enhancement of contrast between the metal deposits and BY40 yellow stained background. CAF, then VMD, only led to extra detail being observed on nylon-Lycra. Other techniques investigated were 1,8-diaza-9-fluorenone (DFO), small particle reagent (SPR), ninhydrin, fluorescent powders and the use of a sputter coater for alternative VMD metals.

It was also uncovered that both VMD and CAF processes were affected by the addition of water to the surface of the fabrics being processed, and although marks and ridge detail were still detected, CAF was less effective than VMD. The production of carbon nanoparticles from different sources in an attempt to introduce and entirely novel fingerprint reagent was unsuccessful but new knowledge was gained. Finally, the issue of ridge detail being obscured by the fabric weave may have been resolved by the use of IR photography or FFT processing.

Also, three papers (Appendix 16.2), based on the work described in this thesis, have been published with a further paper on the collaborative DNA work with Ignacio Quinones Garcia having been submitted to Forensic Science International Genetics. All the papers were submitted to scientific peer review journals therefore their acceptance and publication reinforces the previous statement of original contribution.

14. FUTURE WORK

There are many areas that need to be investigated, within the area of fingermark recovery from fabrics, and possible further work could include:

- To determine if the use of a one-step fluorescent cyanoacrylate (CA) will be effective on fabric and solve the problem of background fluorescence from the dye portion of the cyanoacrylate fuming (CAF) process.
- The use of an alternative to basic yellow 40 (BY40) for the staining of the CA polymer.
- Lifting marks visualised on the fabrics using vacuum metal deposition (VMD) or CAF or a combination of the two, to see if this can combat the problem that the weave pattern of the fabric causes on the recording of fingermark ridge detail observed.
- Investigate and refine the use of fast Fourier transform (FFT) and infrared (IR) imaging in relation to visualising fingermarks on fabric.
- Examine, in much more detail the fingerprint residues themselves and how they interact with the fabrics, how much they penetrate into the surface of the fabric, as well as how they spread across the surface.
- To investigate the use of the Adroit FC-300 and metal sublimation to determine whether identifiable latent marks can be visualised on fabrics

14.1 To determine if the use of a one-step fluorescent cyanoacrylate will be effective on fabric and solve the problem of back ground fluorescence from the dye portion of the CAF process.

This one-step process would have two advantages, the first being, as the name suggests that it is a one-step process, so the items only have to be placed in the CAF cabinet and processed. Secondly, the items do not have to go through a separate dyeing stage, which would provide additional benefits:

- a decrease in time of visualisation of fingermarks;
- the fabrics would not need to be submerged in a dye, which, in the case of BY40, contains a solvent that could have a detrimental effect on the fabric, such as shrinkage or warping and therefore effect the marks that may be found on the fabric;

- a possible reduction in the uptake of dye by the fabrics themselves, which may result in a decrease in possible background fluorescence, thus less obscuring of any possible marks.

The development of a fluorescent cyanoacrylate has previously been investigated with varying levels of success. Weaver and Clary (1993) introduced a portable Vapor Wand, which was developed in conjunction with 3M. This wand was the size of a pen and could be used in the field, due to the use of "rechargeable cartridges of cured cyanoacrylate" which also included a proprietary subliming dye from 3M that was magenta in colour, thus visible marks could be developed within 20 seconds on multiple substrates. However, when they tried to scale up the equipment they encountered a few problems, such as the polymer building up on the tubing within the set-up causing them to become blocked. This was in part solved by the use of larger replaceable tubing and the addition a petroleum jelly coating over the fixtures. Gros, Spring and Deinet (1995) tried to alter the chemical structure of CA so that it would fluorescent, but this was unsuccessful as they found that the ethyl ester adduct produced from reacting anthracene with ethyl cyanoacrylate generally decomposed and did not lead to a fluorescing CA. Similar problems were experienced by the Israel National Police during their 2008 experiments (cited in Ramotowski 2012) where they used Diels-Alder adducts of anthracene with ethyl cyanoacrylate, though this time the compound covered the whole surface of the production as it sublimed too fast, thus no fingermarks were developed. This work has continued and several companies have come up with products, such as CN-Yellow, which is marketed by Arrowhead Forensics (2010), and fluorescent CA monomers produced by Bentolila et al. (2013) in Israel.

In Britain, there are two fluorescent CA formulations on the market at the moment – PolyCyano UV from foster+freeman and Lumiocyano™ from Global Forensics. The major difference between them being that PolyCyano needs a modification to the CA cabinet so it heats to the required 230 ºC, whereas Lumiocyano™ can be used in any CA cabinet without modification. On the foster+freeman website (2013), they state that PolyCyano can be used to visualise marks "without the need for further chemical treatment". Thus, once the marks are developed and removed from the cabinet they can be visualised using long wave UV lighting at the wavelength of 365 nm and the marks recorded. The PolyCyano can be used in a standard CAF cabinet, however a modification does need to be made as material needs to be heated to 230 ºC, whereas as the standard cabinets only heat to 120 ºC. This increase in temperature is a concern, as heating CA to temperatures above 200 ºC can lead to the production of toxic hydrogen cyanide fumes, therefore health and safety issues (Mock 1985; Fung et al. 2011). The other product on the market, Lumiocyano™, does not have this issue as it is used at the standard temperature of 120 ºC and works on porous and non-porous substrates. It and can be viewed under UVA lighting at the optimum excitation of 325 nm, but can also be viewed using alternative light sources with a blue green waveband of 425-530 nm (Global Forensics 2013).

As both products are readily available they should both be investigated as to their suitability of visualising fingermarks on fabrics, however the Lumiocyano™ would be the easier product to start with as no modifications to the normal CAF cabinet would be necessary.

14.2 The use of an alternative to BY40 for the staining of the CA polymer

Many dyes have been tested in the UK in conjunction with CAF and the preferred and operational choice is BY40. As BY40 was originally a textile dye (Wilkinson 1996) this causes many problems with the dyeing of fabric articles after CAF processing. More dye will be absorbed by porous fabrics than non-porous therefore background fluorescence often obscures any marks, marks and detail that may be on the surface. Therefore, the investigation of alternative dyes, such as europium chelate and ardrox, to be used after CAF could alleviate this problem as. Cummings, Hollars and Trozzi (1995) examined several fluorescent dyes, including the aforementioned ardrox, and suggested that there are many other dyes that have not been, but should be, tested in fingerprinting as the best one may not have yet been found. Some of these were examined in a small study that was carried out by a final year student at Abertay University comparing BY40 to ardrox, rhodamine 6G and europium chelate solutions but this resulted in little success. A study similar to that of Mazzella and Lennard (1995), found that BY40 visualised more marks and they were of higher detail than any of the other dyes. However this may be due to unsuitable light sources that were not illuminating in the correct wavelength, thus it may be useful to repeat this study (Aitken 2011. pers. comm., 22 April). Thus, europium chelate should be re-examined in relation to recovery of fingermarks from fabrics. There is documented evidence that it has been successful on other substrates such as human skin (Wilkinson and Watkin 1993; Allred and Menzel 1997), a variety of plastic bags

(Wilkinson and Misner 1993), paper (Allred and Menzel 1997; Wilkinson 1999) and metals (Lock, Mazzella and Margot 1995).

The use of such as food colourings and "festival powders" to highlight the polymer rather than dyeing the fabric is also another possible alternative to BY40. There have been several studies into the use of food colourings and spices as visualisers for latent marks. For example, Garg, Kumari and Kaur (2011a) discussed the use of turmeric to visualise fingermarks on paper (office, bond and thermal), acetate sheets, foil, varnished wood, plastic, painted steel and CDs, all of which ranged in porosity. The turmeric was milled to an extremely fine powder then sprinkled onto the substrate and the excess tapped off to leave an obvious mark on all the substrates. Later they described the use of orange red, lemon yellow and bright green synthetic food colourants in, as well as red, green and pink "gulal" festival colours, in on paper, foil, aluminium metal and CDs. These powders were again sprinkled onto the substrates and excess removed by tapping. On paper the colourants were not as successful as traditional fingerprint powders, however on the foil and CDs they were better. There is of course the added benefit that these colourants were much more readily available and cheaper to purchase (Kumari, Kaur and Garg 2011b). Thus, the use of these powders after CAF or even on the fabric without previous treatment may work well and should be investigated. However, like the fluorescent powders, they may be deemed too messy a technique leading to a coloured fabric with no visualisation. There may also be an impact on DNA recovery therefore this would also need to be investigated.

14.3 Lifting marks visualised on fabrics using VMD or CAF or a combination of the two, to see if this can combat the problem that the weave pattern of the fabric causes on the recording of fingermark ridge detail observed

There is an issue with fingermarks on fabric in that the operator may see excellent ridge detail on the fabric being examined, however once photographed the ridge detail is obscured or disguised by the weave of the fabric. Therefore lifting the visualised marks from the original substrate may solve, or at least reduce, this issue by removing the effect of the weave. This was suggested by Collins, Coles and Stroud (1973), however they unsuccessfully attempted lifts with adhesive tapes as the metals did not completely separate from the fabrics. They also tried dampened photographic paper with more success, leading to "very satisfactory print transfers", therefore this should be further investigated. Though this might be carried out operationally and a small amount of research has been done (see Raymond section 3.23, p. 80-84) no further work has been published. Therefore other types of lifts such as fingerprint lifting tape and gelatine lifts that are used to obtain marks such footwear marks and impressions in blood should also be investigated. These types of lifts may not have the problem that the adhesive tapes have in that the remove the background as well as the mark. If the gelatine lifters could just remove the visualised marks, the metals in the case of VMD or the polymer in the case of CAF, the background weave of the fabric would not be on the lift. Therefore, the effect of this on the ridge detail will be diminished or removed all together leaving the level of detail normally observed by the naked eye.

14.4 Investigate and refine the use of FFT and IR imaging in relation to visualising fingermarks on fabric

As demonstrated in section 3.24 FFT and IR imaging successfully removed a great deal of the fabric weave pattern from many of the photographs of VMD and CAF enhanced marks, enabling the ridge detail to be more easily viewed therefore this is an area that should be investigated further.

In a book chapter Kamei (2004) explained the use of FFT in the reduction of noise and the removal of backgrounds to enhance and improve the contrast between the ridges and valleys of a mark. Thus, by choosing the correct filters (frequency and directional) based on image size and resolution, the minutiae, ridges and valleys become clearer and this aids identification. With IR imaging CA is a good candidate as the radiation will interact with carbon, triple bond, nitrogen (C≡N) functional group within the CA and it is generally free from any interference within the 2000 cm^{-1} range of the spectrum. Tahtouh et al. (2005) showed that IR chemical imaging on marks deposited on plain glass (microscope slides), polymers, banknotes and ceramics worked well. Items with patterned backgrounds, such as the polymer banknotes could be processed with CAF, stained, then subjected to IR imaging which effectively removed the background and thus reduced interference allowing the ridge detail to be more easily observed.

Consequently, an in depth investigation on the use of FFT and IR imaging could be very beneficial in enhancing marks on fabric. Many of the marks within the various areas of this study have resulted in empty marks and through the work carried out by collaborators (Paul Deacon on VMD and Jennifer Raymond CAF) both techniques have proved useful in enhancing visual detail further.

14.5 Examine, in much more detail the fingerprint residues themselves and how they interact with the fabrics, how much they penetrate into the surface of the fabric, as well as how they spread across the surface

It would be interesting and helpful to work out exactly what was happening with the fingermarks after they were deposited on to each fabric type, as this might help the operator decide which visualisation technique would be most suitable to use on the specific item being examined.

Almog et al. (2004) found that the print residues penetrated to different levels depending on the paper type and chemical enhancement technique. With smooth paper they tended to remain on the surface only penetrating to a depth of 18 - 36 microns, whereas with filter paper the residues penetrated deeper to between 99 and 138 microns. Therefore, in many cases, the chemical treatments used were actually working within the paper and thus the visualisation was affected by how deep the residues had penetrated and a correlation was observed with a depth of 40 – 60 microns deemed as the "optimum penetration depth" to produce the best prints. The model used by Almog et al. on paper could be expanded to fabrics as they are thought to behave in a similar fashion to the different types on paper. As discussed in chapter 8.6, some fabrics are more absorbent than others. Nylon tends to allow moisture to sit on the surface, therefore it could be that the fingerprint residues are doing the same, whereas linen tends to absorb water into and through its surface to the underside, so would fingerprint residues do the same? Therefore if the fabrics were tested in a similar way, as paper, it might help decide whether it would be useful or even worthwhile to attempt the use of VMD, CAF or another technique to visualise latent fingermarks on a certain fabric type.

14.6 To investigate the use of the Adroit FC-300 and metal sublimation to determine whether identifiable latent marks can be visualised on fabrics.

The Adroit FC-300 latent mark development system has been successfully used with aluminium to visualise high level ridge detail and identifiable latent marks on a variety of substrates, such as apples, bottles, CDs and condoms (Knaggs, C. 2010. pers. comm., 2 August). Some preliminary work has also been carried out on fabric swatches using dye sublimation to visualise latent marks and grabs. As previously stated in Section 11.1 these results were not as successful as those visualised with aluminium though they did show promise. Therefore, as Knaggs, determined it was possible to visualise identifiable marks on non-porous substrates, further work should be carried out to determine whether metals other than aluminium, such as silver or gold+zinc would be more successful in visualising latent marks on fabrics.

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16. APPENDICES

16.1 Appendix 1 - DNA data from Ignacio Quinones Garcia

Table 16.1: SGM Plus DNA analysis of donor 2 containing DNA reference profile, analysis of treated sample (t2.1 and t2.2) as well as untreated sample (u2.1 and u2.2), along with dropin alleles (other).

	2		t2.1			t2.2			u2.1			u2.2		
Locus	Allele 1	Allele 2	Allele 1	Allele 2	Other	Allele 1	Allele 2	Other	Allele 1	Allele 2	Other	Allele 1	Allele 2	Other
D10S1248	14	15	14	15	13,16	14	15		14	15	13, 17	14	15	13, 16
vWA	17	19	17	19	14, 15	17	19		17	19	18	17	19	14, 18
D16S539	11	12	11	12		11	12		11	12		11	12	
D2S1338	20	22	20	22		20			20	22			22	
Amelogenin	X	X	X	X		X	X	Y	X	X		X	X	Y
D8S1179	12	13	12	13	11, 14	12	13	14	12	13	14	12	13	14
D2S11	31.2	32.2	31.2		28, 29		32.2		31.2	32.2	28	31.2	32.2	
D18S51	15	15	15	15		15	15		15	15		15	15	18
D22S1045	15	16	15	16			16		15	16		15	16	11
D19S433	14	15.2	14	15.2		14	15.2		14	15.2	11, 12	14	15.2	12, 13
ThO1	9	9	9	9		9	9		9	9	9.3	9	9	
FGA	21	21	21	21	20	21	21		21	21	20	21	21	
D2S441	14	14	14	14		14	14		14	14		14	14	
D3S1358	16	17	16	17	15	16	17		16	17	15	16	17	14
D1S1656	12	12	12	12	14.3	12	12		12	12	14	12	12	11
D1S391	18	18	18	18					18	18		18	18	
			31		11	27		2	32		11	31		12

Table 16.2: SGM Plus DNA analysis of donor 5 containing DNA reference profile, analysis of treated sample (t5.1 and t5.2) as well as untreated sample (u5.1 and u5.2), along with dropin alleles (other).

	5		t5.1			t5.2			u5.1			u5.2		
Locus	**Allele 1**	**Allele 2**	**Allele 1**	**Allele 2**	**Other**	**Allele 1**	**Allele 2**	**Other**	**Allele 1**	**Allele 2**	**Other**	**Allele 1**	**Allele 2**	**Other**
D10S1248	13	13	13	13	14, 15	13	13	14	13	13	14, 15, 16	13	13	14, 15
vWA	14	17	14	17		14	17		14		18	14	17	
D16S539	11	12	11	12		11			11	12				
D2S1338	17	20	17	20										
Amelogenin	X	Y	X	Y		X	Y		X	Y		X	Y	
D8S1179	10	11	10	11	12, 13	10	11	13, 14	10	11	12	10	11	12
D2S11	29	30	29	30	31.2, 32.2	29			30		32.2	29		
D18S51	12	13	12		15		13		12	13		15	16	
D22S1045	15	16	15	16		15	16	11	15	16		15	16	
D19S433	12	14	12	14	13	12	14	11	12	14	13	12	14	13, 15
ThO1	6	9.3	6		9	6	9.3		6	9.3	9	6	9.3	
FGA	21	23	21	23		21	23							
D2S441	10	14	10	14		10	14	11	14			10	14	11
D3S1358	15	17	15	17		15	17		15		17.2	15	17	16
D1S1656	11	12	12			11					14.3		12	
D1S391	17	18	18		21					18				
			28		10	24		6	21		10	22		7

Table 16.3: SGM Plus DNA analysis of donor 6 containing DNA reference profile, analysis of treated sample (t6.1 and t6.2) as well as untreated sample (u6.1 and u6.2), along with dropin alleles (other).

	6		t6.1			t6.2			u6.1			u6.2		
Locus	Allele 1	Allele 2	Allele 1	Allele 2	Other	Allele 1	Allele 2	Other	Allele 1	Allele 2	Other	Allele 1	Allele 2	Other
D10S1248	15	16	15	16	13		16		15	16		15	16	14, 13
vWA	15	16	15	16	17				15	16	11, 17	15	16	17, 18
D16S539	11	11	11	11		11	11		11	11				11, 12
D2S1338	17	19	17	19					17	19				20, 22
Amelogenin	X	X	X	X		X	X		X	X	Y	X	X	Y
D8S1179	12	13	12	13					12	13		12	13	10
D2S11	29	31	29	31	32.2					31	24, 29.2	29	31	32.2
D18S51	16	17	16	17	9, 13								17	12
D22S1045	15	16	15	16			15	16	15	16		15	16	
D19S433	13	14	13	14		13	14	15.2	13	14		13	14	15.2, 16
ThO1	9.3	9.3	9.3	9.3					9.3	9.3	9	9.3	9.3	9
FGA	19	22	19	22					19		21			20, 22
D2S441	11	12	11	12		11	12		11	12	14	11	12	14
D3S1358	16	17	16	17		16	17		16	17	15	16	17	15
D1S1656	11	16.3	11	16.3	12					16.3				17.3
D1S391	19	20	19	20	18									
			32		7	12		2	25		9	21		20

Table 16.4: SGM Plus DNA analysis of donor 9 containing DNA reference profile, analysis of treated sample (t9.1 and t9.2) as well as untreated sample (u9.1 and u9.2), along with dropin alleles (other).

	9		t9.1			t9.2			u9.1			u9.2		
Locus	Allele 1	Allele 2	Allele 1	Allele 2	Other	Allele 1	Allele 2	Other	Allele 1	Allele 2	Other	Allele 1	Allele 2	Other
D10S1248	14	15	14	15	13				14			14	15	13
vWA	17	17	17	17										19
D16S539	11	12	11	12								11		
D2S1338	17	19	17	19	20									
Amelogenin	X	X	X	X					X	X		X	X	Y
D8S1179	11	11			13, 15									
D2S11	27	30		30	30.2, 31.2									
D18S51	12	18			15									
D22S1045	11	11			16							11	11	14, 16
D19S433	14	14.2	14		13, 15							14		
ThO1	9.3	9.3			7							9.3	9.3	9
FGA	21	22.2								14				
D2S441	12	14		14	10, 11							12	14	11
D3S1358	15	17.2												16
D1S1656	12	14.3	12									12		
D1S391	18	19.3										18		
			14		9	0		0	4		0	14		8

Table 16.5: SGM Plus DNA analysis of donor 11 containing DNA reference profile, analysis of treated sample (t11.1 and t11.2) as well as untreated sample (u11.1 and u11.2), along with dropin alleles (other).

	11		t11.1			t11.2			u11.1			u11.2		
Locus	Allele 1	Allele 2	Allele 1	Allele 2	Other	Allele 1	Allele 2	Other	Allele 1	Allele 2	Other	Allele 1	Allele 2	Other
D10S1248	15	17	15	17	14	15	17		15		16	15	17	13, 16
vWA	15	18	15	18		15	18		15	18		15	18	16
D16S539	10	12	10	12		10	12		10	12		10	12	11, 13
D2S1338	18	20	18	20		18	20						20	25
Amelogenin	X	Y	X	Y		X	Y		X	Y	X	X	Y	
D8S1179	13	13	13	13	14	13	13		13	13	12	13	13	
D2S11	30	31	30	31		30	31		30	31	28, 32.2	30	31	29
D18S51	14	14	14	14		14	14		14	14	13, 15	14	14	
D22S1045	15	15	15	15		15	15		15	15	16	15	15	16
D19S433	13	14	13	14	15.2	13	14		13	14	15.2	13	14	
ThO1	7	9.3	7	9.3		7	9.3				9	7	9.3	9
FGA	23	25	23	25	21	23	25				20, 21	23	25	24
D2S441	10	13	10		14	10	13		10	13	12	10	13	14
D3S1358	15	15	15	15	16	15	15		15	15	17	15	15	16, 17
D1S1656	17	17.3	17	17.3	12	17	17.3		17		12	17	17.3	15.3
D1S391	19	21				19	21				18	19	21	20
			29		7	32		0	22		15	31		15

Table 16.6: SGM Plus DNA analysis of donor 13 containing DNA reference profile, analysis of treated sample (t13.1 and t13.2) as well as untreated sample (u13.1 and u13.2), along with dropin alleles (other).

	13		t13.1			t13.2			u13.1			u13.2		
Locus	**Allele 1**	**Allele 2**	**Allele 1**	**Allele 2**	**Other**	**Allele 1**	**Allele 2**	**Other**	**Allele 1**	**Allele 2**	**Other**	**Allele 1**	**Allele 2**	**Other**
D10S1248	13	14	13	14	16	13	14		13	14	15		14	
vWA	17	17	17	17		17	17	19	17	17	19			15
D16S539	10	11	10	11		10	11			11				
D2S1338	17	17	17	17	20	17	17							
Amelogenin	X	Y	X	Y	X	X	Y		X			X	Y	
D8S1179	11	13	11	13	14	11	13	14	11	13	12		13	12
D2S11	29	31.2	29	31.2		29	31.2			31.2		29		27
D18S51	18	18	18	18	15	18	18	12				18	18	13
D22S1045	15	17	15	17	16		15	11	15	17	16	15		16
D19S433	12	13	12	13	14	12	13	14	12	13	15.2		13	14
ThO1	9	9.3	9	9.3	6	9	9.3	8	9	9.3				
FGA	20	22	20	22	21	20	22	21	20		21	20		19
D2S441	10	11	10	11	14	10	11	14	10	11	14			14
D3S1358	16	17	16	17	15	16		17	16	17		16		15
D1S1656	15	15.3	15	15.3	17.3	15	15.3	12			12			13, 17.3
D1S391	20	21	20	21	18			17			18			20.3
			32		13	28		11	20		9	11		11

Table 16.7: SGM Plus DNA analysis of donor 15 containing DNA reference profile, analysis of treated sample (t15.1 and t15.2) as well as untreated sample (u15.1 and u15.2), along with dropin alleles (other).

	15		15.1t			15.2t			15.1u			15.2u		
Locus	Allele 1	Allele 2	Allele 1	Allele 2	Other	Allele 1	Allele 2	Other	Allele 1	Allele 2	Other	Allele 1	Allele 2	Other
D10S1248	13	16	13	16	14, 17	13			13	16	14, 17	13	16	15
vWA	17	18	17	18	16, 15, 19				17	18	16, 19	17	18	19
D16S539	9	11		11	12, 14						12	9	11	12
D2S1338	21	24										21	24	
Amelogenin	X	Y	X	Y		X	Y		X	Y		X	Y	
D8S1179	12	14	12	14	10, 13		14		12	14	13	12	14	13
D2S11	30	30.2	30		28, 31.2				30	30.2	28	30	30.2	29
D18S51	14	15										14	15	
D22S1045	14	16	14	16	15	14	16			16	11, 15, 17	14	16	15
D19S433	15	15			11, 12, 13,14	15	15	14			13, 14	15	15	14, 13
ThO1	6	9.3		9.3			9.3		6	9.3	9	6	9.3	9
FGA	18	24			21, 13			21			21	18	24	21
D2S441	10	14	10	14	11	10	14		10	14	11, 15	10	14	12
D3S1358	15	17	15	17	16, 18		17		15	17	16	15	17	16
D1S1656	13	13			12						12, 16.3	13	13	12
D1S391	18	24		18	17				18	20.3				17.3
			18		20	12		2	19		19	30		14

Table 16.8: SGM Plus DNA analysis of donor 16 containing DNA reference profile, analysis of treated sample (t16.1 and t16.2) as well as untreated sample (u16.1 and u16.2), along with dropin alleles (other).

	16		16.1t			16.2t			16.1u			16.2u		
Locus	Allele 1	Allele 2	Allele 1	Allele 2	Other	Allele 1	Allele 2	Other	Allele 1	Allele 2	Other	Allele 1	Allele 2	Other
D10S1248	13	14	13	14		13	14		13	14		13	14	15
vWA	18	19	18	19		18	19		18	19		18	19	17
D16S539	10	12	10	12		10	12		10	12		10	12	11
D2S1338	19	20	19	20		19			19	20		19	20	22
Amelogenin	X	X	X	X		X	X		X	X		X	X	
D8S1179	13	15	13	15		13	15	12	13	15		13	15	12
D2S11	30	31	30	31		30	31		30	31		30	31	31.2
D18S51	15	17	15	17		15			15	17		15		
D22S1045	16	16	16	16		16	16		16	16		16	16	15
D19S433	13	15	13	15	10	13	15		13	15		13	15	14, 15.2
ThO1	6	7	6	7		6	7		6	7		6	7	9
FGA	21	22.2	21	22.2		21	22.2		21	22.2		21		
D2S441	11	15	11	15		11	15		11	15	14	11	15	14
D3S1358	15	17	15	17		15	17		15	17		15	17	16
D1S1656	12	13	12	13		12	13		12	13		12	13	
D1S391	17	18	17	18		17	18		17	18		17	18	
			32		1	31		1	32		1	30		12

Table 16.9: SGM Plus DNA analysis of donor 20 containing DNA reference profile, analysis of treated sample (t20.1 and t20.2) as well as untreated sample (u20.1 and u20.2), along with dropin alleles (other).

	20		20.1t			20.2t			20.1u			20.2u		
Locus	Allele 1	Allele 2	Allele 1	Allele 2	Other	Allele 1	Allele 2	Other	Allele 1	Allele 2	Other	Allele 1	Allele 2	Other
D10S1248	16	17	16	17	15				16	17	14, 15	16	17	15
vWA	18	19	18	19	17	18	19		18	19	14, 15	18	19	
D16S539	11	12	11	12		11	12		11	12	13	11	12	
D2S1338	17	17	17	17		17	17	22	17	17	20	17	17	
Amelogenin	X	Y	X	Y					X	Y		X	Y	
D8S1179	10	14	10	14	13	10	14	12	10	14	12, 13	10	14	11, 13, 14
D2S11	27	29	27	29					27	29		27	29	31.2
D18S51	14	18	14	18					14	18	13	14	18	
D22S1045	15	16	15	16		15	16		15	16		15		11
D19S433	13	14	13	14	12				13	14		13	14	12
ThO1	7	8	7	8					7	8	6	7	8	9
FGA	22	25	22	25					22	25		22	25	24
D2S441	11	15	11	15	14	11	15	14	11	15	14	11	15	14
D3S1358	15	16	15	16					15	16		15	16	17
D1S1656	14	17.3	14	17.3					14	17.3		14	17.3	16.3
D1S391	22	25	22	25					22	25	18	22	25	18
			32		5	12		3	32		12	31		13

16.2 Appendix 2 - Publications

The published articles in Appendix 2 (pp. 321-337) have been removed to comply with UK Copyright Law. The article citations are listed below.

16.21

Fraser, J., Sturrock, K., Deacon, P., Bleay, S. and Bremner, D. H. 2011. Visualisation of fingermarks and grab impressions on fabrics. Part 1: Gold/zinc vacuum metal deposition. *Forensic Science International*. 208(1): pp. 74-78. doi:10.1016/j.forsciint.2010.11.003

16.22

Knighting, S., Fraser, J., Sturrock, K., Deacon, P., Bleay, S and Bremner, D. 2013. Visualisation of fingermarks and grab impressions on dark fabrics using silver vacuum metal deposition. *Science and Justice*. 53(3): pp. 309-314. doi:10.1016/j.scijus.2013.01.002

16.23

Fraser, J., Deacon, P., Bleay, S. and Bremner, D. H. 2014. A comparison of the use of vacuum metal deposition versus cyanoacrylate fuming for visualisation of fingermarks and grab impressions on fabrics. *Science and Justice*. 54(2): pp. 133-140. doi:10.1016/j.scijus.2013.11.005